MICROCONTROLLER DRIVEN SENSOR BASED SPEED CONTROL OF BRUSHLESS DC MOTOR

PROJECT REPORT

Submitted by

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In partial fulfillment of the requirements for the award of the degree
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DEPARTMENT OF ELECTRICAL AND ELECTRONICS ENGINEERING
KUMARAGURU COLLEGE OF TECHNOLOGY
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CERTIFICATE

This is to certify that the project report entitled

MICROCONTROLLER DRIVEN SENSOR BASED SPEED CONTROL OF BRUSHLESS DC MOTOR

Is the bonafide work done by

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In partial fulfillment of the requirements for the Award of the degree of Bachelor of Engineering in Electrical and Electronics Engineering Branch of Bharathiar university, Coimbatore.

Guide

Head of the department

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th March, 2004

TO WHOMSOEVER IT MAY CONCERN

This is to certify that the following Final Year B.E.,(Electrical and Electronics) students of The Kumaraguru College of Technology, Coimbatore, has done project work in our organization on "**MICROCONTROLLER DRIVEN SENSOR BASED SPEED CONTROL OF BRUSHLESS DC MOTOR** " in partial fulfillment of their academic requirement .

Name of the Students:

Miss.S.Poornima

Miss.N.Prabha

Mr.C.Selvaraj

Mr.V.Mohanraj

Period of project: **June 2003 to February 2004.**

Department: **Engineering**

During this period their attendance and conduct were good.

We wish them all success in their future endeavors.

Thanking You,

Yours Faithfully,
For Elgi Electric and Industries Ltd.

M.MANICKAM
MANAGER-H.R.D

Acknowledgement

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Abstract

ABSTRACT

DC brushless motors are similar in performance and application to brush-type DC motors. Both have a speed vs. torque curve which is linear or nearly linear. The motors differ, however, in construction and method of commutation.

A brush-type permanent magnet DC motor usually consists of an outer permanent magnet field and an inner rotating armature. A mechanical arrangement of commutator bars and brushes switches the current in the armature windings to maintain rotation. A DC brushless motor has a wound stator, a permanent magnet rotor assembly, and internal or external devices to sense rotor position.

The magnetic sensing Hall-Effect sensors provide signals for electronically switching (commutating) the stator windings in the proper sequence to maintain rotation of the magnet assembly. The rotor assembly may be internal or external to the stator in a DC brushless motor. The possible number of phases and winding arrangements for the DC brushless stator are quite varied. The winding arrangement may be either a Y or a delta configuration. For our project, we have chosen a stator with four phases connected in Y configuration.

The combination of an inner permanent magnet rotor and outer windings offers the advantages of lower rotor inertia and more efficient heat dissipation than DC brush-type construction. The elimination of brushes reduces maintenance, increases life and reliability and reduces noise and EMI generation.

In the case of brush type DC motors, increasing the number of phases reduces torque ripple. This is true with the Brushless DC Motor also. It may be noted that the Y configuration with a lead common to the four phases can be commutated in a unipolar mode with only four electronic switches. However, the motor torque is reduced with this scheme.

The sensor signals are given to the microcontroller which is programmed to find out the correct phase sequence and switch them accordingly. The speed of the BLDC motor is controlled by varying the time for which each phase has to be energized.

Cost, operating environment of the motor, intended application and performance all influence the choice.

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BRUSHLESS MOTORS – A DEVELOPING TECHNOLOGY

Brushless DC motors offer definite advantages in certain applications. So, should we automatically choose a brushless DC? After all, we're familiar with DC motors. Well, comparing brushless DC motors to brush-type motors may have a significant impact on our final decision.

In the conventional DC motors, the brushes, by design, wear out faster than the motor. We have to replace them if we want to keep using that motor. After a few brush changes, it's not unusual for us to have a worn commutator. Since expected brush life is difficult to predict, the typical solution is to replace brushes well before they completely wear out.

Continuous improvements in the brush materials have led to significant improvements in the service of the mechanical commutator. The electronically commutated Brushless DC motor is the other alternative. The additional cost for the electronics of the BLDC motor is compensated by the almost unlimited service life.

1.1 Introduction to Brushless D.C (BLDC) motor

A brushless DC motor is a rotating electric machine where the stator is a classic four-phase stator like that of an induction motor and the rotor has surface-mounted permanent magnets. In this respect, the BLDC motor is equivalent to a reversed DC commutator motor, in which the magnet rotates while the conductors remain stationary. In the DC commutator motor, the commutator and brushes alter the current polarity. On the contrary, in the brushless DC motor, power transistors switching in synchronization with the rotor position perform the polarity reversal. Therefore, BLDC motors often incorporate either internal or external position sensors to sense the actual rotor position or the position can be detected without sensors.

1.2 Comparison with conventional DC motors

	Conventional motors	**Brushless motors**
Mechanical structure	Field magnets on the stator	Field magnets on the rotor (Similar to AC synchronous Motor)
Distinctive features	Maintenance problems	Long-lasting Easy maintenance (usually No maintenance required)
Commutation method	Mechanical contact between brushes and commutator	Electronic switching using transistors
Detecting method of Rotor's position	Automatically detected by brushes	Hall element, optical encoders, etc.
Reversing method	By reversing the terminal voltage	By reversing the switching sequence

1.3 Significant features of BLDC motors

Tight speed regulation:

Applications requiring especially reliable speed regulation benefit from using brushless DC motors. We get precise control because the brushless DC motor gives the controller feedback from the motor's commutation sensors. These sensors (usually the Hall Effect type) give a direct measure of rotor speed, rather than relying on indirect methods.

The common brush-type SCR speed controls rely on an indirect measure of armature speed by reading the back-EMF generated by the motor. The back-EMF constant (or voltage constant) is a function of the motor's winding resistance, which in turn is a function of the winding temperature. As a motor warms up, its winding resistance changes, and this causes the measured speed to "drift." Some SCR controls have a temperature-compensation circuit. Unfortunately, these circuits don't completely resolve the problem. This is especially true when the motor is operating at the low end of its speed range, or if it is driving a very light load. As a result, we might set the speed of the machine, only to find that it is running too fast an hour later.

However, a brushless DC motor and control system will give the same output peed regardless of changes in motor temperature.

Low audible noise:

Manufacturers of medical centrifuges typically use series-wound brush-type motors because of their high operating speed (up to 15,000 rpm). However, at such high speed, the brushes make significant noise as they rub the commutator. The ventilated motors add to the overall noise, as their fans push air through dozens of tiny crevasses. By comparison, a non-ventilated brushless DC motor at the same speed is virtually silent.

Low EMI:

Brush-type motors produce EMI because of arcing at the brush centers. In applications having very stringent noise standards, like office equipment we may have to add filter capacitors, line filters, or shielding to contain the EMI generated by a brush-type motor. In brushless motors, since there is no electromagnet in the rotating part, the Electro Magnetic Interference (EMI) is greatly reduced.

Small size:

The heat-generating part of a brush-type DC motor is the armature winding, in the center of the motor. The heat-generating part of a brushless DC motor is the stator winding, which is close to the outside surface of the motor. Since it's easier for heat to dissipate from the outside of the motor than from the inside, the thermal resistance of the brushless DC motor is lower. Thus, we can produce more continuous power before exceeding the temperature limit than we could with a brush-type. This means a smaller brushless DC motor can provide the same continuous power output as a larger brush-type DC motor. Any product designed for portability can benefit from a lighter and smaller motor.

No brush dust:

Brushless DC motors obviously produce no brush dust. This makes them desirable for clean-room environments. Applications could include food processing machinery or semiconductor handling equipment.

Lower rotor inertia:

In a brushless DC motor, the bulky winding sits in the stationary part of the motor. In a brush-type motor, the winding is in the rotating part. Thus, the latter motor has to accelerate and stop a higner inertial mass (winding plus rotor). This makes the brushless DC motor a good choice for positioning applications.

Energy-efficient:

By using a brushless DC motor rather than an inverter-driven three-phase motor, the Series motor's power consumption is greatly reduced.

1.4 Methodology of the work

This project discusses the construction of Brushless DC motors along with the electronic circuitry and its speed control. The methodology involved is as follows:

- Motor design and construction
- Design of electronic commutation unit
- Design of power circuit
- PCB fabrication
- Keyboard and LCD interfacing
- Speed Control of the motor through AT89C51 programming

2

MOTOR DESIGN AND CONSTRUCTION

DC brushless motors are similar in performance and application to brush-type DC motors. Both have a speed vs. torque curve, which is linear or nearly linear. The motors differ, however, in construction and method of commutation. A brush-type permanent magnet DC motor usually consists of an outer permanent magnet field and an inner rotating armature. A mechanical arrangement of commutator bars and brushes switches the current in the armature windings to maintain rotation. There are two types of brushless DC motors: the type that has an outer rotating magnet assembly, and the "inside out" type that has an inner rotating magnet assembly.

2.1 Inside-Out Mechanical Design

A motor with an inner rotor has a low rotor inertia, which enables attainment of higher acceleration rates, since the acceleration torque required is the product of total inertia times acceleration rate, plus load/friction torque.

Another advantage of the lower inertia, inner rotor is the level of rotor balance attainable in the system. This advantage enables smooth operation at higher speeds (approximately 9,000 RPM to 12,000 RPM). Thus the inner rotor has a high-speed limitation of about 15,000 RPM, whereas the outer rotor has a limitation of about 30,000 RPM.

2.2 Stator Design

The stator consists of steel frames, which, encloses a hollow cylindrical core made up of thin laminations of silicon steel to reduce hysteresis and eddy current loss. A number of evenly spaced slots are provided on the inner periphery of the lamination. The insulated conductors are placed in the stator slots and are suitably connected to form a balanced 4-phase star or delta-connected circuit. The 4-phase stator winding is wound for a definite number of poles.

Concentric Windings of the stator

Concentric windings are single layer or double layer windings, which use concentric type of coils. The coil span of the individual coils is different. The coil span of some coils is more than a pole pitch while the span of the others is equal to or less than the pole pitch. These windings are so designed that the effective coil span of the winding is equal to that of a winding as a full pitch winding with some of the coils having a span greater than a pole pitch some with less than a pole pitch but an effective span which makes the winding behave as if it had full pitched coils.

2.3 Rotor Design

Elimination of commutator and brushes reduces frictional losses and replacing the rotor windings with permanent magnet minimizes eddy current losses in the rotor, thus improving the efficiency. Four types of permanent magnet rotor are commonly used

2.3.1 Types of Rotor Designs

Surface-Mounted Magnets

The radially magnetized permanent magnets are mounted on a steel rotor structure. Since the relative permeability of the magnet material is near unity, it acts like a large air gap. The effective air gap is therefore large, making L_d low. The structure is magnetically non-salient.

Inset Magnets

In the inset arrangement, the permanent magnets are inserted in the steel rotor structure. This construction provides a more secure magnet setting .In this configuration, for the same magnet size, the peak torque developed with inset magnets is higher than for the surface mounted magnets because of the reluctance torque developed with the former.

Interior (Buried) PM with Radial Magnetization

In this arrangement, the magnets are buried inside the rotor structure, with radial magnetization. The q-axis inductance is larger than the d-axis inductance ($L_q > L_d$) and both these values are larger than their corresponding values in surface-type and inset-type rotors.

Interior (Buried) PM with Circumferential Magnetization

Because of the flux-focusing effect, circumferential magnetization yields greater air gap than radial magnetization. The d-axis inductance is large and the structure is magnetically salient. Ferrite magnets have low flux density. The circumferential magnetization arrangement is particularly advantageous for ferrite magnets because a substantial increase in flux density can be achieved.

2.3.2 Our choice of Rotor Design

Simpler and easier construction being our main constraint, we have opted for the surface-mounted magnets. These magnets, because of constant magnetic gap between the stator and rotor, can provide a square wave flux distribution. In BLDC motors, the rotor flux is essentially constant because of the permanent magnet. In the surface-type rotor, since Ld is low, a very large current is required to provide effective field weakening. This rotor configuration is therefore used for constant torque operation.

2.3.3 Magnet Selection

Magnet selection for all applications must consider the entire magnetic circuit and the environment. One of the oldest members of our magnet family, Alnico remains the workhorse of the permanent magnet industry and can be relied upon to deliver impressive flux density at an economical price. Alnico also boasts the lowest temperature coefficient of any commercial magnet material (.02% per degree centigrade) allowing for excellent stability over a wide temperature range. Alnico has experienced renewed interest in recent years in such temperature-sensitive applications as hall-effect and MR-based automotive and electronic sensors, in addition to the traditional magnetron, TWT amplifiers, actuators, motors and instruments applications that have long relied upon Alnico.

Stability and Temperature Effects of Alnico Magnets

Alnico magnets offer excellent stability with respect to temperature changes: reversible change is 0.02% per degree Centigrade. Heating may produce an irreversible loss of magnet strength. The magnitude of loss depends upon the dimensions of the magnet and its composition, but is usually less than 5%, and may be recovered by re-magnetization. At temperatures exceeding 1000°F (538°C), a metallurgical change takes place which causes magnetic strength to reduce rapidly. This change will not be recovered by re-magnetization. External magnetic fields can also induce partial demagnetization. In some critical applications, it is desirable to stabilize the magnet by intentionally reducing magnetic output by 5% to 10%. Such stabilization may reduce, or even eliminate, the effect of stray external fields.

Electronic Commutation

3

ELECTRONIC COMMUTATION

The possible number of phases and winding arrangements for the DC brushless stator are quite varied. As in the case of brush-type DC motors, increasing the number of phases reduces torque ripple. However, an important practical consideration for DC brushless motors is the number of electronic switches required to commutate the phases. Four phase motors provide a compromise in this regard and so we've opted this.

3.1 Hall Effect Sensors

Rotor position sensing is essential for proper commutation of DC brushless motors. Magnetic sensing with inexpensive Hall Effect sensors is frequently adequate. The devices require little space and can easily be placed within the motor. Optical encoders or resolvers may also be used. Cost, operating environment of the motor, intended application and performance all influence the choice.

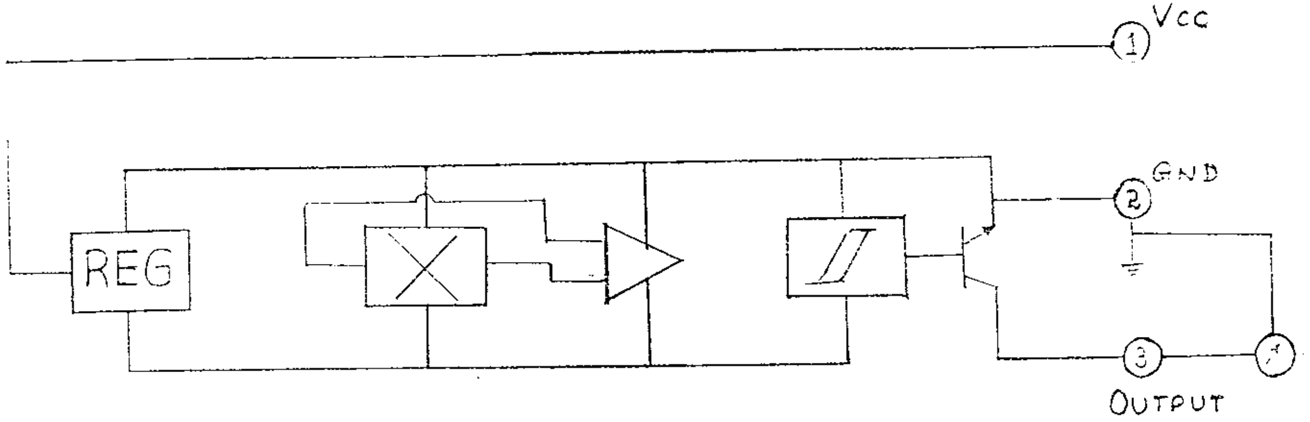
The function of a Hall sensor is based on the physical principle of the Hall effect named after its discoverer E. H. Hall: It means that a voltage is generated transversely to the current flow direction in an electric conductor (the Hall voltage), if a magnetic field is applied perpendicularly to the conductor. As the Hall effect is most pronounced in semiconductors, the most suitable Hall element is a small platelet made of semi conductive material

These sensors respond to the presence or the interruption of a magnetic field by producing a low output and turn high if the magnetic field is removed. The output remains high in the absence of magnetic field.

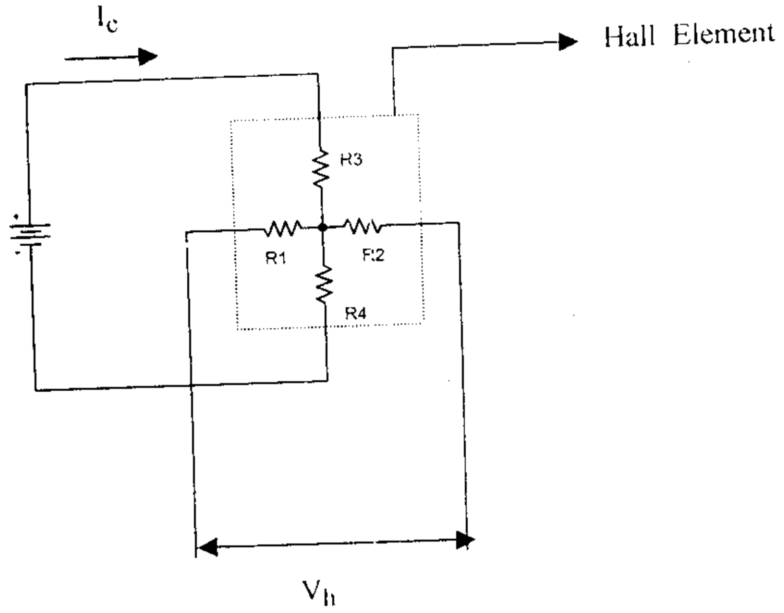
HALL-EFFECT SENSOR

HI-300

FUNCTIONAL BLOCK DIAGRAM

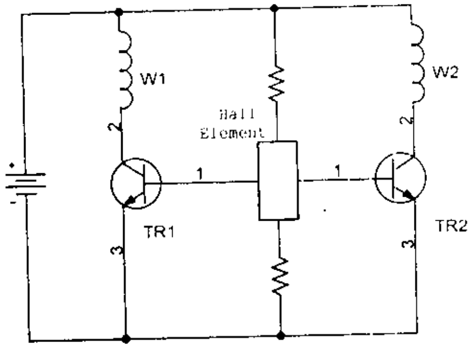


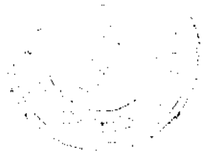
Principle of Position Detection using Hall elements.



This figure shows the equivalent circuit for a Hall element expressed as four-terminal network. When a current I_c, which is called the control current or bias current, flows through resistors R_3 and R_4 in the Hall element exposed to a magnetic field which is perpendicular to the element plane, a voltage V_h is generated across the other two terminals. Thus when a Hall element is placed near a permanent magnet rotor, the Hall element can accurately detect the pole positions.

Principle of working of the simplest brushless DC motor using one Hall element



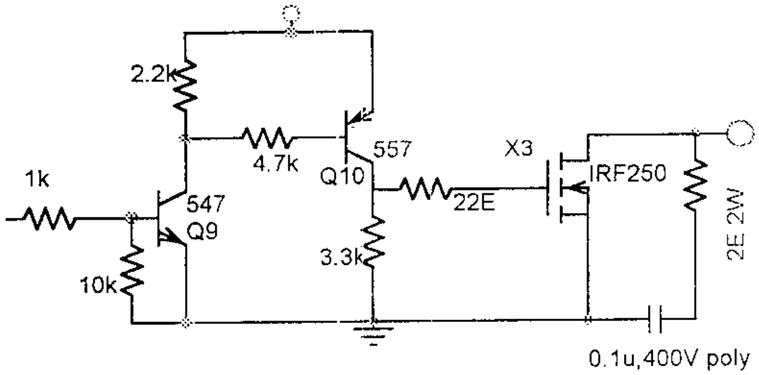


- The output signals from the Hall element operate two transistors TR_1 and TR_2 to control the electrical currents in stator windings W_1 and W_2.
- The Hall element detects the north pole of the rotor magnet, and winding W_2 is energized to produce the South Pole, which drives the rotor in the CCW direction
- Since no magnetic field is applied to the Hall element in this positional relation, both transistors are in the OFF state, and no currents flow in W_1 or W_2. The rotor continues to revolve due to inertia
- The Hall element detects the south pole of the rotor, and winding W_1 is energized to created the south pole which attracts the north pole of the rotor to continue the CCW motion.

3.2 Power Transistors

Commutation of a four phase motor with current reversal requires that the windings be switched every 90 electrical degrees. If four sensing devices are spaced 90 electrical degrees apart, four switching signals are to be produced at 90 degree intervals as the rotor turns. Each change of state triggers switching of the stator windings to a particular terminal pair and polarity. Power MOSFETs are used for this purpose. The power MOSFET is a voltage-controlled device and requires only a small input current. The switching speed is very high and switching time is of the order of nanoseconds.

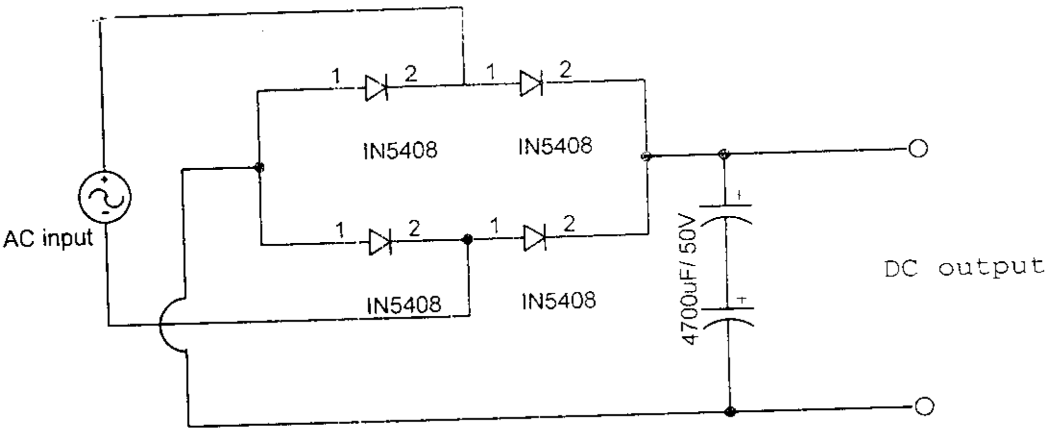
Power Transistors in driving circuit



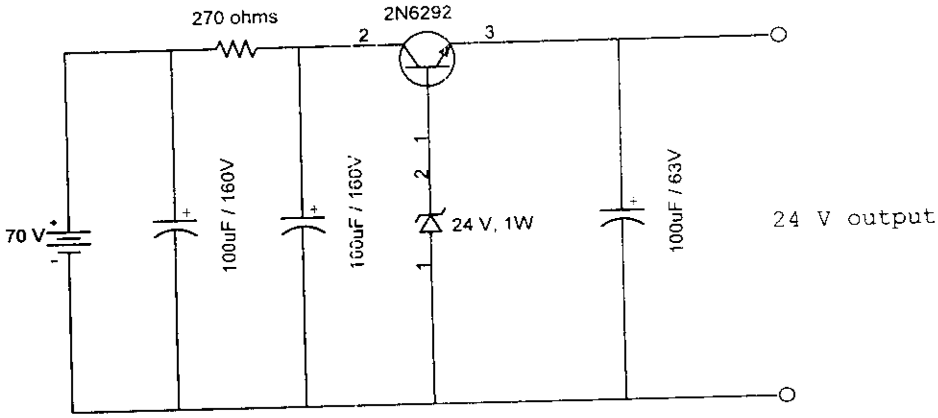
This is the driving circuit which switches the corresponding winding in sequence. The pre-amplifying circuit consists of two transistors BC547 and BC557 which amplify the sensor signals before they are sent to trigger the gate of the MOSFET.

3.3 Power Supply Unit

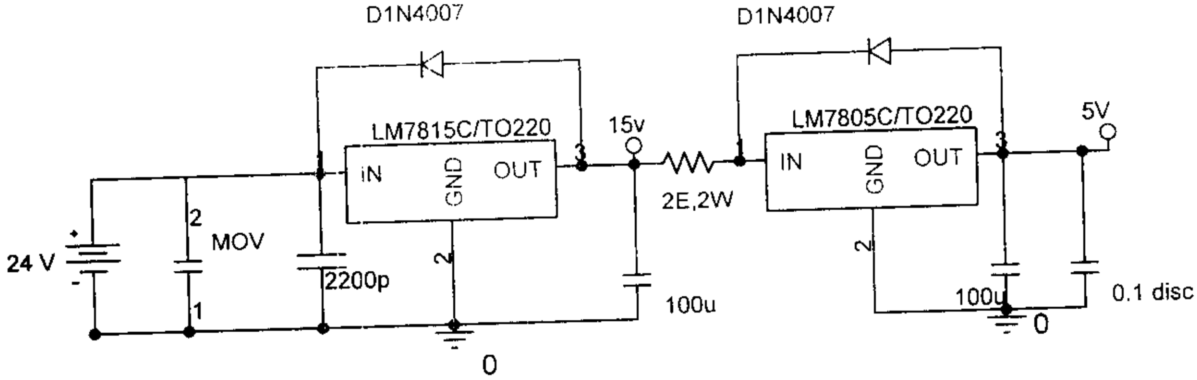
Rectifier Circuit



Regulator Circuit

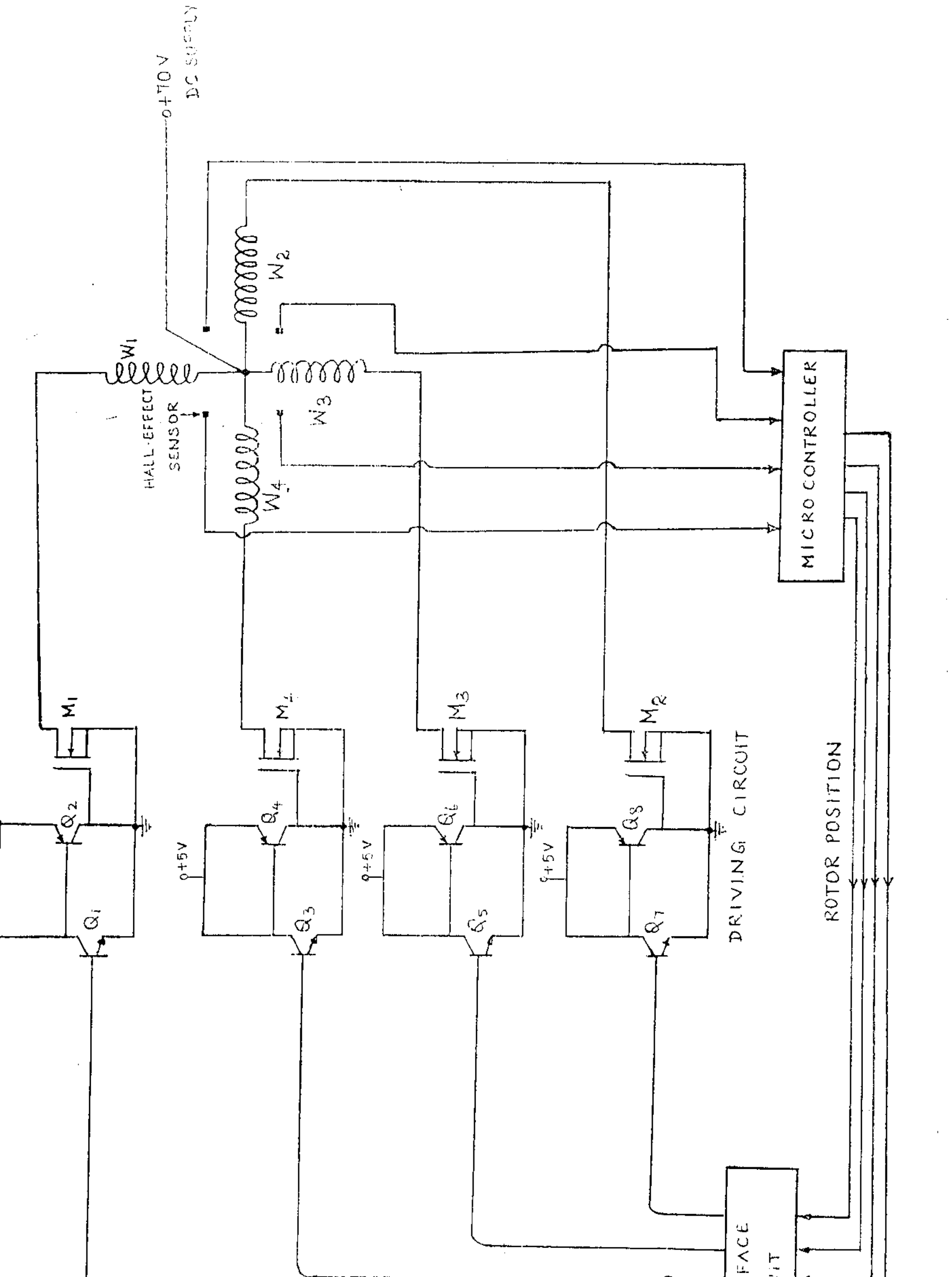


Power Supply for PCB

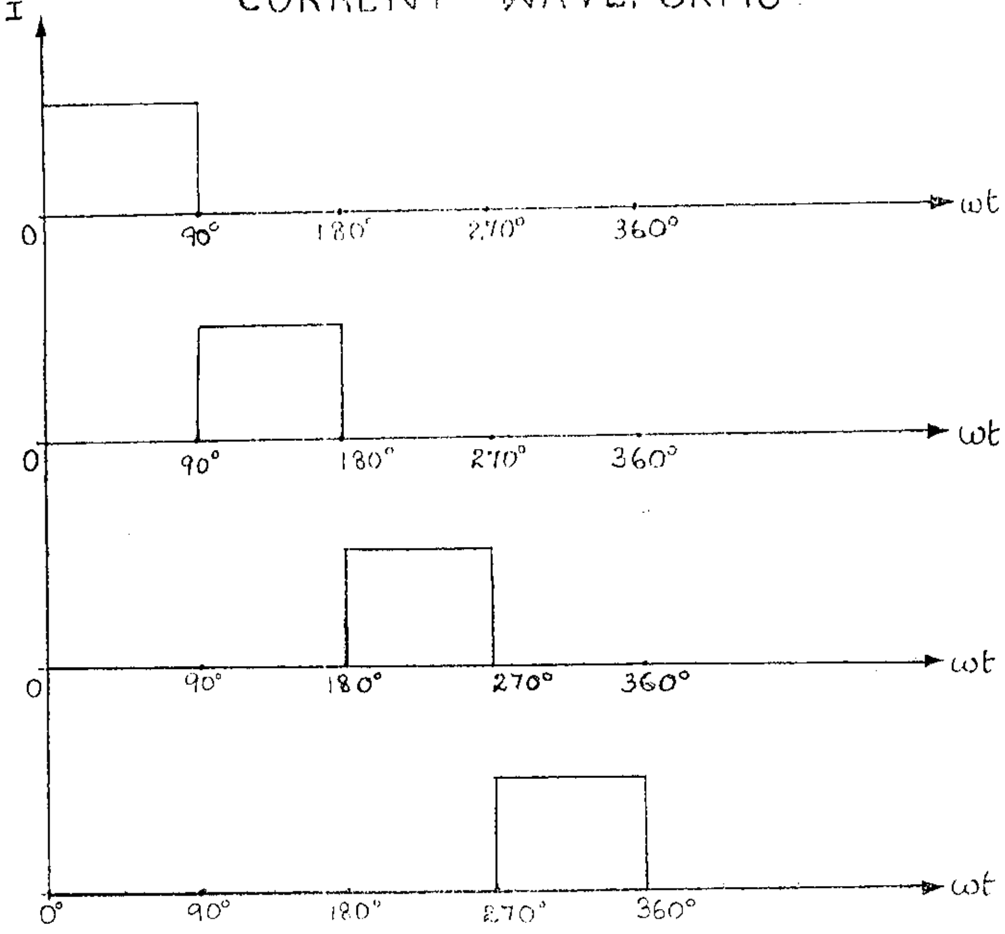


A DC voltage of 70V has to be given to the motor. Due to the unavailability of a constant DC of the required voltage, a 230V AC supply is varied to 50V using a variac so that a DC voltage of 70V is obtained in the rectifier circuit. This voltage is regulated to 24V using the regulator circuit.

The PCB is fed with the regulated 24V to supply the driving circuit, sensors, the programming and the regulator ICs .Two regulator ICs – LM7805C and LM7815C are used for providing 5V and 15V respectively.


+70 V
DC SUPPLY
W1
W2
W3
W4
HALL-EFFECT
SENSOR
MICRO CONTROLLER
M1
M4
M3
M2
Q2
Q1
Q4
Q3
Q6
Q5
Q8
Q7
+5V
+5V
+5V
DRIVING CIRCUIT
ROTOR POSITION
FACE

4-PHASE UNIPOLAR (90°)
CURRENT WAVEFORMS



4

PCB FABRICATION

4.1 Introduction to OrCAD

OrCAD offers a total solution for the core design tasks namely the schematic and VHDL based design entry; FPGA and CPLD design synthesis; digital, analog, and mixed-signal simulation; and printed circuit board layout. What's more, OrCAD's products suit a variety of applications built around an engineer's design flow, it's not just a collection of independently developed point tools. For example, OrCAD Capture is just one element in OrCad's total solution design flow.

Many of today's electronic circuits combine analog and digital components. While working with both analog and digital circuits, we need a Simulator that can handle mixed-signal circuits. Using OrCAD Capture, we can create schematics for analog or mixed signal designs, printed circuit board layout designs, and programmable logic designs.

4.2 Schematic Page creation

OrCAD Capture design entry is the most widely used schematic entry system in electronic design today for one simple reason: it's the fast and universal design entry scheme. From designing a new analog circuit, or revising schematic diagrams for an existing PCB, to hierarchical design block and to take the circuit for simulation, the latest version of OrCAD Capture provides everything we need to expedite our design from verification to manufacturing.

Capture's schematic page editor helps us to efficiently create our design. After the design is created, Capture's tools are used to quickly annotate them and prepare them for the next stage of development.

Capture stores all of a design's schematics, schematic pages and parts in a single file. This makes it easy to handle our designs. A Capture design contains one or more schematic folders, and each schematic folder contains one or more schematic pages, and a design is a collection of related schematic folders.

4.3 Layout

OrCAD Layout is a powerful circuit board layout tool that has all the automated functions we need to quickly complete the board. Using OrCAD Capture, a Layout compatible net list can be created. The net list contains much of the design information that Layout uses to produce the board.

In Layout, we need to set up the environment while creating a new board design. The steps for setting up the board are as follows:

- Define resource files and target directory for the design.
- Select the units for measurement
- Create the board outline
- Define the layer stack
- Set system grids
- Specify the component types used in the design
- Define the manufacturing technology and complexity
- Set spacing rules
- Define pad stacks
- Define vias
- Set color settings for the graphical display of the design

4.4 Placing Components

The next step in the design flow is placing components. The components can be placed individually or in groups. Before placement, it should be ensured that the design has a board outline that is present on all layers and that all obstacles are established.

The steps involved are as follows:

- Check if any pre-placed components is properly placed
- Lock the components on the board so that they won't get moved when other components are placed.
- Create the height keepins and keepouts. A height keepin contains all components above or below a specified height. A height keepout excludes components at or above the specified height.

- To place components individually, choose the component tool bar button.
- In the component selection criteria dialogue box, type the name of the component to place.
- From edit menu, choose select next. The component displays attached to the pointer. Drag the component and place it by clicking the left-mouse button.
- To check for placement violations, choose design rule check from the auto menu. Select the placement spacing violation option in the dialogue box. Then choose the OK button.
- Placement statistics are available by choosing the spreadsheet toolbar button, then choosing statistics.

4.5 Routing

After the components are placed on the board, the electrical connections between the components can be routed. Before we begin routing, we need to set net properties, enable the routing layers, and specify routing parameters. The steps involved are as follows:

- The plane layers must be routed first.
- Power and Ground through-hole pairs are automatically routed to the appropriate plane layers and assigned thermal relieves.
- Choose Add Via from the pop up menu to the appropriate plane layer.
- When power and ground routing is finished, those nets are disabled.
- To manually route a track, choose the shove track toolbar button, then select a pad and drag the pointer to draw a segment. Layout suggests a via as you route the track.
- Pressing the ALT key and clicking the left mouse button on a track can begin a new track on another track of the same net. This is known as T-routing.
- Selecting a track and pressing the "L" shortcut key can lock a track. This prevents the auto router from shoving it or ripping it up.
- When routing has been finished, the routing statistics can be viewed in the statistics spreadsheet.

Keyboard And Display Interfacing

5

KEYBOARD AND DISPLAY INTERFACING

The required speed for which the motor has to be run is entered through the keyboard and is also displayed on the LCD. The speed is also stored in the controller's memory for further calculations. The entry and display processes necessitate an interface between the keyboard, display and the microcontroller.

5.1 Keyboards

The predominant interface between humans and computers is the keyboard. The universal key characteristic is the ability to bounce: the key contacts vibrate open and closed for a number of milliseconds when the key is hit and often when it is released. These rapid pulses are not discernible to the human, but they last a relative eternity in the microsecond-dominated life of the microcontroller. Keys may be purchased that do not bounce, or keys may be debounced with RS flip-flops or debounced with time delays.

Keyboard Configuration

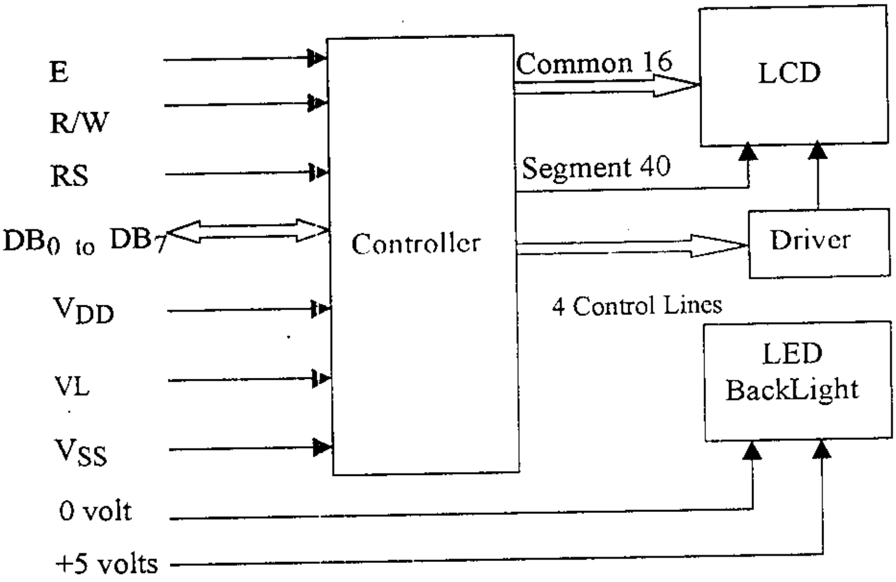
The lead-per-key configuration is used, as there are very few keys to be sensed. Each key is connected to the Port 0 pins of the microcontroller to serve the following purpose:

- KEY 1 : Set Key
- KEY 2 : Increment Key
- KEY 3 : Decrement Key
- KEY 4 : Digit Selection Key
- KEY 6 : Mode Key

5.2 Liquid Crystal Displays

If keyboards are the predominant means of interface to human input, then visible displays are the universal means of human output. We have used the Alphanumeric LCD Module ODM-16216-9 for our project.

Block Diagram of ODM-16216-9



Function Description of ODM

It has two 8 bit registers, an Instruction Register (IR) and a Data Register (DR). The IR stores the instruction codes and address information for Display Data Ram (DD RAM) and Character Generator Ram (CG RAM). The IR can be written, but not read by the MPU.

The DR temporarily stores data to be written from the DD RAM or CG RAM. The data written to DR by the MPU, is automatically written to the DD RAM or CG RAM as an internal operation.

When an address code is written to IR, the data (of the specified address) is

DD RAM or CG RAM to the DR. Data transfer between the MPU is then completed when the MPU reads the DR. Likewise, for the next MPU read of the DR, data in DD RAM or CG RAM at the next address is sent to the DR automatically. Similarly, for the MPU write of the DR, the next DD RAM or CG RAM address is selected for the write operation.

Busy Flag

When the busy flag is 1, the controller is in internal operation mode, and the next instruction will not be accepted.

When RS = 0 and RW = 1, the busy flag is output to DB7.

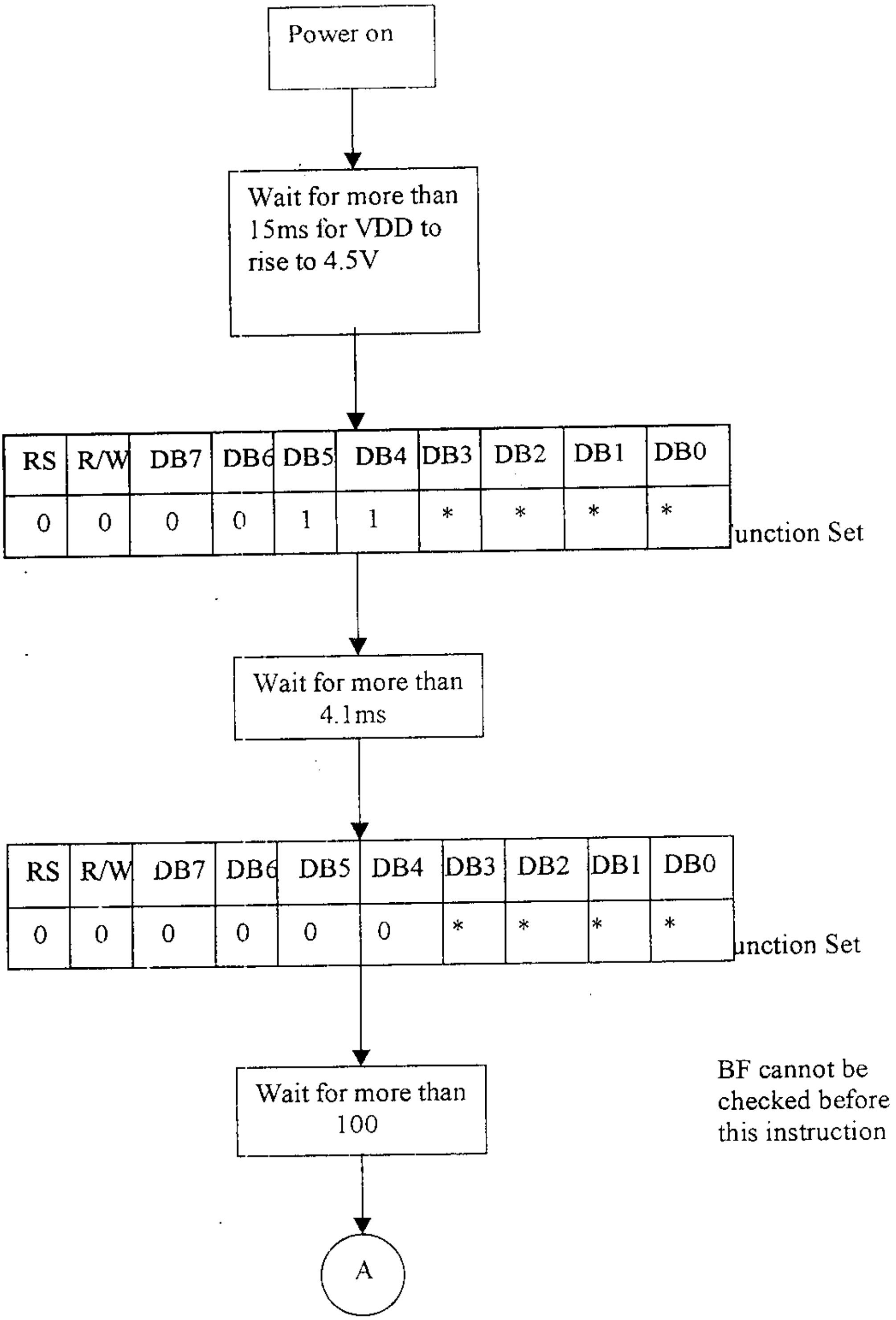
The next instruction must be written after ensuring that the busy flag is 0.

Timing Characteristics of ODM

The ODM doesn't have the conventional chip select (CS) terminal. When the ODM is directly to the data bus of microcontroller, the enable signal (E) has to be derived from CS or Input Select. The critical timing parameters are the enable pulse width of 450ns and the data delay timing during read cycles of 320ns.

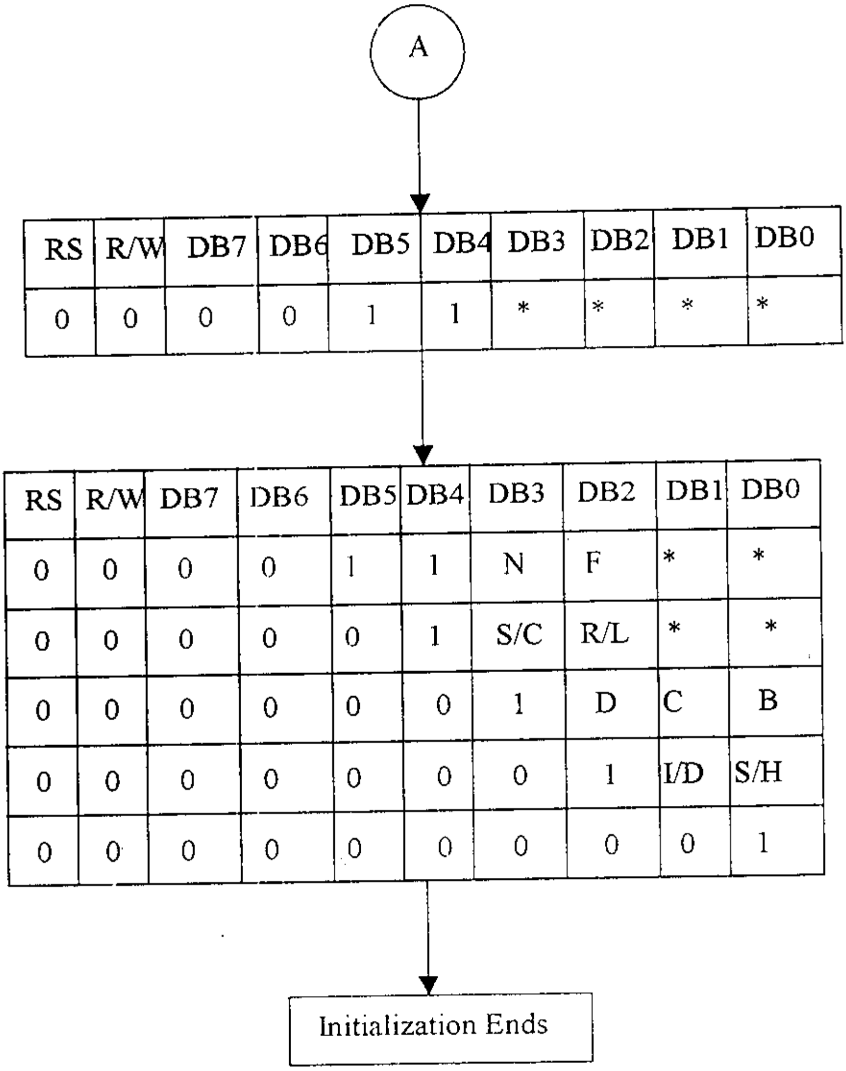
5.3 LCD INITIALISATION

The following procedure should be carried out to initialize the Module by instruction.



RS	R/W	DB7	DB6	DB5	DB4	DB3	DB2	DB1	DB0
0	0	0	0	1	1	*	*	*	*

RS	R/W	DB7	DB6	DB5	DB4	DB3	DB2	DB1	DB0
0	0	0	0	0	0	*	*	*	*



RS	R/W	DB7	DB6	DB5	DB4	DB3	DB2	DB1	DB0
0	0	0	0	1	1	*	*	*	*

RS	R/W	DB7	DB6	DB5	DB4	DB3	DB2	DB1	DB0
0	0	0	0	1	1	N	F	*	*
0	0	0	0	0	1	S/C	R/L	*	*
0	0	0	0	0	0	1	D	C	B
0	0	0	0	0	0	0	1	I/D	S/H
0	0	0	0	0	0	0	0	0	1

5.4. LCD INSTRUCTION TABLE

Instruction	CODE										
	RS	R/W	DB7	DB6	DB5	DB4	DB3	DB2	DB1	DB0	Description
Clear Display	0	0	0	0	0	0	0	0	0	1	Clears entire display and returns cursor to home position (Address0)
Return Home	1	0	0	0	0	0	0	0	1	*	Returns the cursor to the home position (Address 0) Also returns display being shifted to original position. DD RAM contents remains unchanged.
Entry Mode Set	0	0	0	0	0	0	0	0	I/D	S	Select cursor move direction and specifics shift of display. These operations are performed during data write and read
Display ON/OFF Control	0	0	0	0	0	0	1	D	C	B	Sets ON/OFF of entire display (D) cursor ON/OFF (C) and blink of cursor position character (B)
Cursor or Display Shift	0	0	0	0	0	1	S/C	R/L	*	*	Move cursor and shift display without changing DD RAM contents

Function Set	0	0	0	0	I	DL	N	F	*	*	Set interface data length (DL), number of linc (N)(and character font (F)
Set CG RAM Address	0	0	0	I	AGG						Set CG RAM address. CD RAM data is sent and received after this setting.
SET DD RAM Address	0	0	1	Add							Sets DDR AM address DD RAM data is sent and received after this setting.
Read Busy Flag & Address	0	1	BF	AC							Read Busy flag (BF) indicating internal operations are being performed and reads address counter contents
Write Data to CG or DD RAM	1	0	Write Data								Write data into DD RAM or CG RAM
Read Data from CG or DD RAM	1	1	Read Data								Read data

I/D =1 : Increment

I/D=0 : Decrement

S=1 : Accompanies display shift

S/C=1 : Display shift

S/C =0 : Cursor move

DL=1 :8 Bits and DL =0 : 4 Bits

N=1 : 2 lines and N=0 :1 line

R/L = 1 : Shift to Right

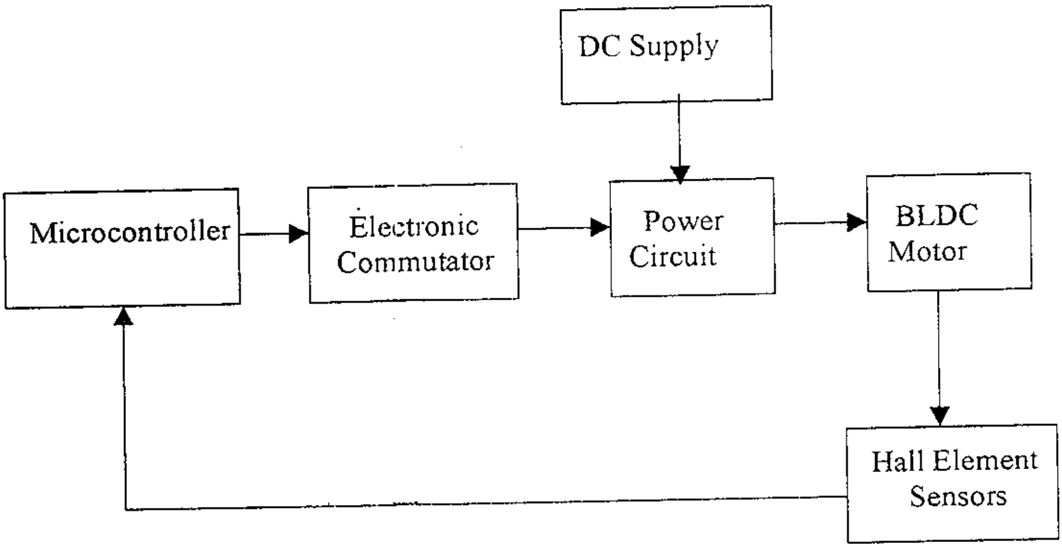
R/L =0 : Shift to Left

Speed Control

6

SPEED CONTROL

6.1 Control Principle



DC supply of +5V is given to the power circuit and 70V is given to the BLDC motor. Four Hall Element sensors are placed on the outer cover of the motor each 90-degree apart. A small magnet is fixed on a thin steel rod connected to the outer end of the shaft in such a way that the magnet passes close by to the sensors as the shaft rotates. These sensors give a low output when a magnet comes close by.

Thus the rotor position is sensed and is given to the microcontroller. Depending on the microcontroller output, the corresponding winding is switched on. The time for which each winding is switched on determines the speed of the motor. By suitably programming the microcontroller, this time can be decreased or increased, which in turn produces corresponding increase or decrease in the speed of the motor.

6.2 Gradual starting of motor

At zero speed the control software has first to determine which phase it should supply. So first of all the code reads the three Hall effect sensor output sequence and applies a voltage on the appropriate phase pair. This operation causes the motor to start rotating. The supplied phase pair is then changed at each Hall sensor output edge. The applied current does not change until the first speed loop entry.

The motor cannot be run directly for the entered speed. So the motor is initially started at a lower speed and is gradually made to run at increasing speeds. Depending on the sensor signals, the corresponding winding is switched on for a predefined time period. After all the four windings are switched on once, the time period is reduced and once again all the four windings are switched on. This process is repeated until the motor runs at a standard final speed.

6.3 Running the motor for the required speed

Once the motor has picked up some initial speed, it is made to run at the entered speed. From the entered speed, the time taken for one revolution is found and each winding is switched on for one-fourth of this time. Thus the motor is made to run at the desired speed.

AT89C51 Programming

7

AT89C51 PROGRAMMING

A miocrocontroller is a general-purpose device, but one that is meant to read data, perform limited calculations on that data, and control its environment based on those calculations. The prime use of a microcontroller is to control the operation of a machine using a fixed program that is stored in ROM and that does not change over the lifetime of the system.

7.1 AT89C51 Microcontrollers

The first and foremost criterion in choosing a microcontroller is that it must meet the task at hand efficiently and cost effectively. The second criterion in choosing a microcontoller is how easy it is to develop products around it and the third criterion is its ready availability in needed quantities both now and in future. Considering all these factors, we have chosen AT89C51 microcontroller for our project.

Features of AT89C51

- 8-bit CPU optimized for control applications.
- Excessive Boolean processing capabilities
- On-chip Flash Program Memory
- On-chip data RAM
- Bi-directional and individually addressable I/O lines.
- Multiple 16-bit Timer/Counter.
- Full duplex UART.
- Multiple source / Vector / Priority Interrupt Structure.
- On-chip oscillator and clock circuitry.
- On-chip EEPROM.
- SPI Serial Bus Interface.
- Watch Dog Timer.

7.1.1 Architecture and Memory Organisation

A micro controller consists of a powerful CPU tightly coupled with memory (RAM, ROM or EPROM), various I/O features like Serial ports ,Parallel ports, Timers/Counters ,Interrupt Controller , Data Acquisition interfaces ,Analog to Digital Converter (ADC) , Digital to Analog Converter (DAC) everything integrated on a single silicon chip.

A microcontroller is preferred to a microprocessor due to the following advantages:

- Size of the board is decreased because the memory required such as RAM, ROM, EPROM, etc., are embedded on a single chip.
- The data transfer is in terms of bits and not in terms of bytes as in real world applications. Hence they can be used for various switching operations.

Functions of various SFRs

1. Accumulator

ACC is the accumulator register. The mnemonics for accumulator – specific instructions refer the register simply as A.

2. B Register

The B Register is used during multiply and divide operations, for other instructions it can be treated as another scratch pad register.

3. Program status word

The PSW register contains the program status information and holds the information about various flags that are set as a result of certain instructions.

4. Stack pointer

The 8-bit wide stack pointer is incremented before data is stored during PUSH and CALL executions. The stack may reside anywhere in the internal RAM area but the stack pointer (SP) is initialized to 07H after reset and the stack begins at location 08H.

5. Data pointer

The Data pointer consists of a high byte (DPH) and a low byte (DPL).

Its intended function is to hold a 16-bit address. It may be manipulated as a 16-bit register or as two independent 8-bit registers.

6. Serial data buffer

The Serial data buffer is actually two separate registers, a transmit buffer and a receive buffer register. When data is moved to SBUF, it goes to the transmit buffer where it is held for serial transmission. When data is moved from SBUF, it comes from the receive buffer.

Power modes of AT89C51 micro controller

To exploit the power savings available in CMOS circuitry, Atmel's Flash microcontroller has two software invited reduced power modes.

- **Idle mode:** The CPU is turned off while the RAM and other on-chip Peripherals continue operating. In this mode current draw is reduced to about 15 percent of the current drawn when the device is fully active.

- **Power down mode:** All on-chip activities are suspended while the on-chip RAM continues to hold its data. In this mode, the device typically draws less than 15 microamperes and can be as low as 0.6 microamperes.

Power on reset

When power is turned on, the circuit holds the RST pin high for an amount of time that depends on the capacitor value and the rate at which it charges. To ensure a valid reset, the RST pin must be held high long enough to allow the oscillator to start up plus two machine cycles .On power-up, V_{CC} should rise within approximately 10ms. The oscillator start-up time is typically 1ms. With the given circuit, reducing Vcc quickly to 0 causes the RST pin voltage to momentarily fall below 0V .However, this voltage is internally limited and will not harm the device.

Memory organization

All Atmel Flash Microcontroller have separate address spaces for program and data memory allows the data memory to be accessed by 8-bit addresses which can be more quickly stored and manipulated by an 8-bit CPU. Nevertheless, 16-bit data memory addresses can also be generated through the DPTR register.

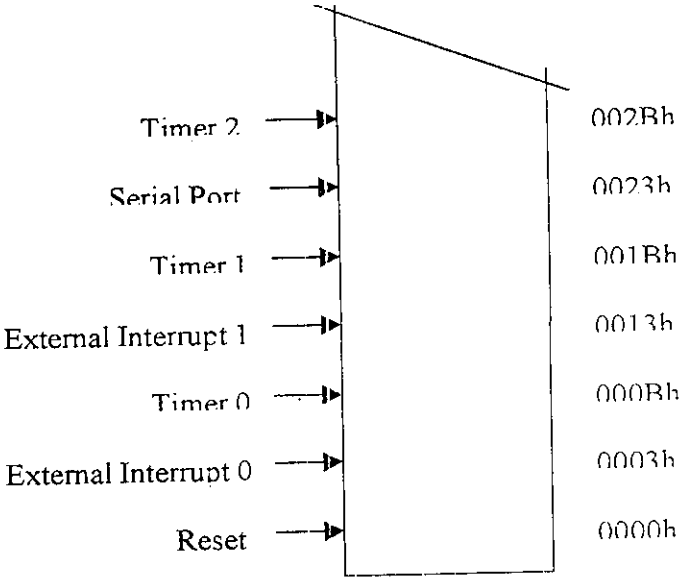
Program memory can only be read. There can be up to 64K bytes of directly addressable program memory. The read strobe for external program memory is the Program Store Enable signal (PSEN) .

Data memory occupies a separate address space from program memory. Up to 64K bytes of external memory can be directly addressed in the external data memory space. The CPU generates read and write signals during external data memory accesses. External program memory can be combined by applying the RD and PSEN signals to the inputs of an AND gate and using the output of the gate as the read strobe to the external program/data memory.

Program memory

The diagram below shows a map of the lower part of the program memory .After reset, the CPU begins execution from the location 0000H. Each interrupt is assigned a fixed location in program memory. The interrupt causes the CPU to jump to that memory location, where it executes the service routine. External interrupt 0, for example, is assigned to the location 0003H. If external interrupt 0 is used, its service routine must begin at location 0003H. If the interrupt is not used, its service location is available as general purpose program memory.

Program Memory



The interrupt service locations are spaced at 8 bytes interval – 0003h for external interrupt 0 , 000Bh for timer 0 , 0013h for external interrupt 1 ,001Bh for Timer 1, and so on. If an Interrupt Service Routine is short enough (as is often the case in control applications),it can reside entirely within that 8 byte interval . Longer service routines can use a jump instruction to skip over subsequent interrupt locations, if other interrupts are in use.

The lowest addresses of program memory can either be in the on-chip Flash or in an external memory. To make this selection, strap the External access (EA) pin to either V_{CC} or GND .

Data memory:

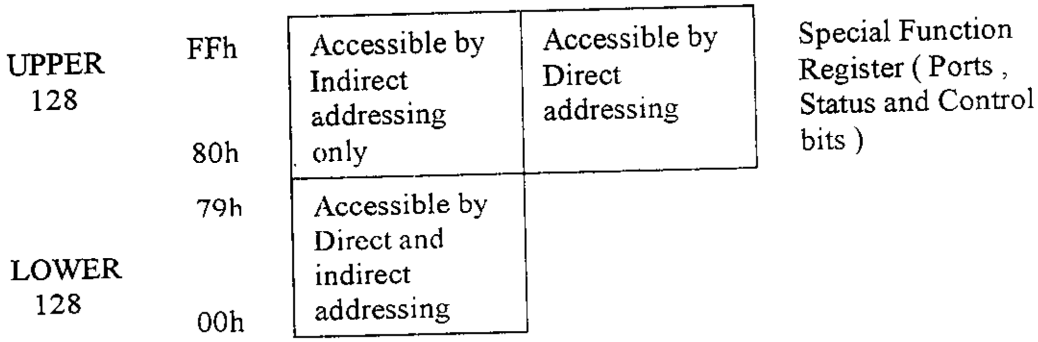
The internal data memory is divided into three blocks namely

1. The lower 128 bytes of internal RAM.
2. The upper 128 bytes of internal RAM.
3. Special function registers.

Internal data memory addresses are always 1 byte wide, which implies an address space of only 256 bytes. However, the addressing modes for internal RAM can infact accommodate 384 bytes. Direct addresses higher than 7Fh access one memory space and indirect addresses higher than 7Fh access a different memory space.

The lowest 32 bytes are grouped into 4 banks of 8 registers. Program instructions call out these registers as R0 through R7. Two bits in the Program Status Word (PSW) Select, which register bank, is in use. This architecture allows more efficient use of code space, since register instructions are shorter than instructions that use direct addressing.

AT89C51 address 0-0FFh registers



The next 16-bytes above the register banks form a block of bit-addressable space. The microcontroller instruction set includes a wide selection of single-bit instructions and these instructions can directly address the 128 bytes in this area. These bit addresses are 00h through 7Fh.

Either direct or indirect addressing can access all of the bytes in lower 128 bytes. The upper 128 bytes can only be accessed by indirect addressing. The upper 128 bytes of RAM are only in the devices with 256 bytes of RAM.

The special function registers include Port latches, timers, peripheral controls, etc. Direct addressing can only access these registers .In general, all Atmel microcontrollers have the SFRs at the same addresses in SFR space as the AT89C51 and other compatible microcontroller. However, upgrades to the AT89C51 have additional SFRs .

Sixteen addresses in SFR space are both byte and bit addressable. The bit addressable SFRs are those whose addresses ends in 000Bh. The bit addresses in this area are 80h through FFh .

Oscillator and Clock Circuit

All Atmel flash Micro Controller have on-chip oscillator that can be used as the clock source for the CPU. To use the on-chip oscillator, connect a crystal between XTAL1 and XTAL2 pins of the Micro Controller and connect capacitors to the ground. The frequency range is in range from 1.2MHz to 12MHz. To drive the chip with an internal oscillator, one would ground XTAL1 and XTAL2. Since the input to the clock generator is divided by two flip-flops there are no requirements on the duty cycle of the external oscillator signal.

Program Status Word

The program status word (PSW) register is an 8-bit register. It is also referred to as the flag register, although the PSW register is 8 bits wide, only 6 bits of it are used by the 8051. The two unused bits are user-definable flags. Four of the flags are called conditional flags, meaning that they indicate some conditions that resulted after an instruction was executed these four are CY (carry), AC (auxiliary carry), P (parity) and OV (overflow).

CY	AC	F0	RS0	RS1	OV	-	P

Symbol	**Bit**	**Function**
CY	PSW.7	Carry flag
AC	PSW.6	Auxiliary carry flag
-	PSW.5	Available to the user for general purpose
RS1	PSW.4	Register Bank selector bit 1
RS0	PSW.3	Register Bank selector bit 0
OV	PSW.2	Overflow flag
-	PSW.1	User definable bit
P	PSW.0	Parity flag

Selection of Register Banks

RS1	**RS0**	**Register Bank**	**Address**
0	0	0	00H – 07H
0	1	1	08H - 0FH
1	0	2	10H – 17H
1	1	3	18H – 1FH

7.1.2 Addressing Modes

The CPU can access data in various ways. The data could be in a register or in memory, or be provided as an immediate value. These various ways of accessing data are called addressing modes. The various addressing modes of a microcontroller are determined when it is designed and therefore cannot be changed by the programmer. The AT89C51 provides a total of five distinct addressing modes. They are as follows:

1) Immediate addressing
2) Register addressing
3) Direct addressing
4) Register indirect addressing
5) Indexed addressing

Immediate Addressing

In this addressing mode, the source operand is a constant. In immediate addressing mode, as the name implies, when the instruction is assembled, the operand comes immediately after the opcode. The immediate data must be preceded by the pound sign, "#". This addressing mode can be used to load information into any of the registers, including the DPTR register.

Register Addressing

Register addressing mode involves the use of registers to hold data to be manipulated. The source and destination registers must match in size. The data can be moved between the accumulator and any of the registers R0 to R7, but the movement of data between the registers is not allowed.

Direct Addressing

In direct addressing, an 8-bit address field in the instruction specifies the operand. Only internal data RAM and SFRs can be directly addressed.

Register indirect Addressing

In Indirect addressing, the instruction specifies a register that contains the address of the operand. Both internal and external RAM and SFRs can be indirectly addressed. The address register for 8-bit addresses can be either the stack pointer or R0 or R1 of the selected register bank.

Indexed addressing

Program memory can only be accessed via indexed addressing. This addressing mode is intended for reading look-up tables in program memory. A 16-bit base register (DPTR or PC) points to the base of the table, and the accumulator is set up with the table entry number. Adding the accumulator data to the base pointer forms the address of the table entry in program memory. Another type of indexed addressing is used in the 'case jump' instructions. In this case, the destination address of a jump instruction is computed as the sum of the base pointer and the accumulator data

7.1.3 I/O Ports

The four ports P0, P1, P2, and P3 each use 8 pins, making them 8-bit ports. All the ports upon RESET are configured as output, ready to be used as output ports. To use any of these ports as an input port, it must be programmed.

Port 0

Port 0 occupies a total of 8 pins (pins 32-39). It can be used for input or output. To use the pins of Port 0 as both input and output ports, each pin must be connected externally to a 10K ohm pull-up resistor. With external pull-up resistors connected upon reset, Port 0 is configured as output port.

Port 1

Port 1 occupies a total of 8 pins (pins 1-8). It can be used as input or output. In contrast to port 0, this port does not need any pull-up resistors since it already has pull-up resistors internally. Upon reset, port 1 is configured as an output port.

Port 2

Port 2 occupies a total of 8 pins (pins 21-28). It can be used as input or output. Just like P1, port 2 does not need any pull-up resistors since it already has pull-up resistors internally. Upon reset, port 1 is configured as an output port.

Port 3

Port 3 occupies a total of 8 pins (pins 10 -17). It can be used as input or output. P3 does not need any pull-up resistors, the same as P1 and P2 did not. Although Port 3 is configured as an output port upon reset, this is not the way it is commonly used. Port 3 has the additional function of providing some extremely important signals such as interrupts.

7.1.4 Timers

- There are two 16 bit timers in microcontrollers.
- Both the timers are up counters.
- There are two control words. They are, **Timer mode**(TMOD) ,**Timer control**(TCON)

Timer control (TCON)

TF1	TR1	TF0	TR0	IE1	IT1	IE0	IT0

TF1 - Timer 1 overflow flag .Set by hardware when the Timer/counter 1 overflows .Cleared by hardware as the processor vectors to the interrupt service routine.

TR1 - Timer 1 run control bit .Set/cleared by software to run Timer/counter 1 ON/OFF.

TF0 - Timer 0 overflow flag .Set by hardware when the Timer/counter 0 overflows .Cleared by hardware as the processor vectors to the interrupt service routine.

TR0 - Timer 0 run control bit .Set/cleared by software to run Timer/counter 0 ON/OFF.

IE1 - External Interrupt 1 edge flag. Set by hardware when the external interrupt edge is detected. Cleared by hardware when the interrupt is processed.

IT1 - Interrupt 1 type control bit .Set/cleared by software to specify falling edge/low level triggered External Interrupt.

IE1 - External Interrupt 0 edge flag. Set by hardware when the external interrupt edge is detected. Cleared by hardware when the interrupt is processed.

IT0 - Interrupt 1 type control bit .Set/cleared by software to specify falling edge/low level triggered External Interrupt.

Timer mode(TMOD)

TIMER1				TIMER0			
GATE	C/T	M1	M0	GATE	C/T	M1	M0

GATE -When TRx (in TCON) is set and GATE =1, Timer/Counterx runs only while the INTx pin is High (hardware control).When GATE =0,Timer/Counterx will run only while TRx=1 (software control).

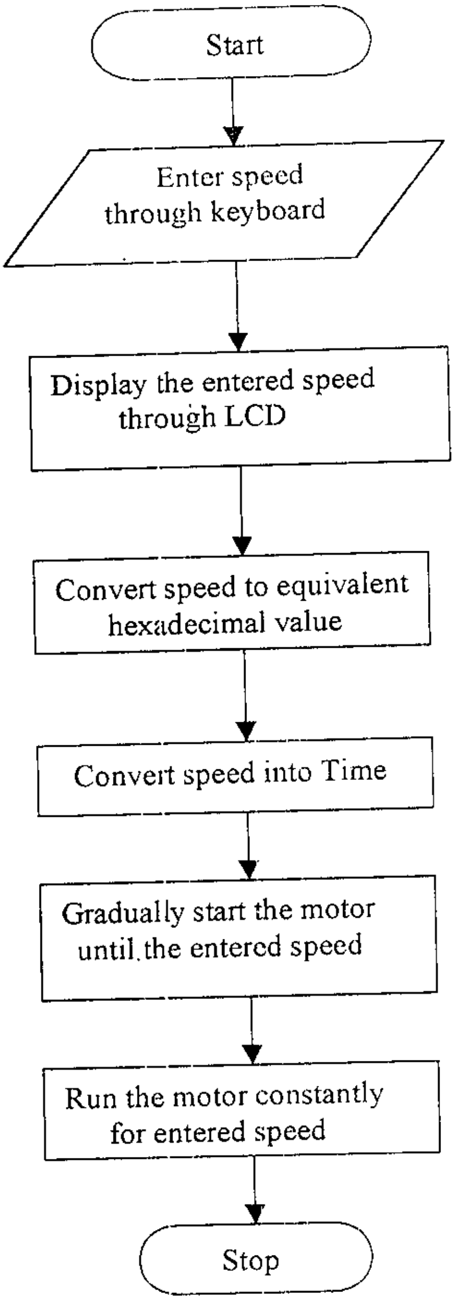
C/T -Timer /counter selector .cleared for timer operation (input from internal timer clock). Set for counter operation (input from Tx input pin).

M1 - Mode selector bit.

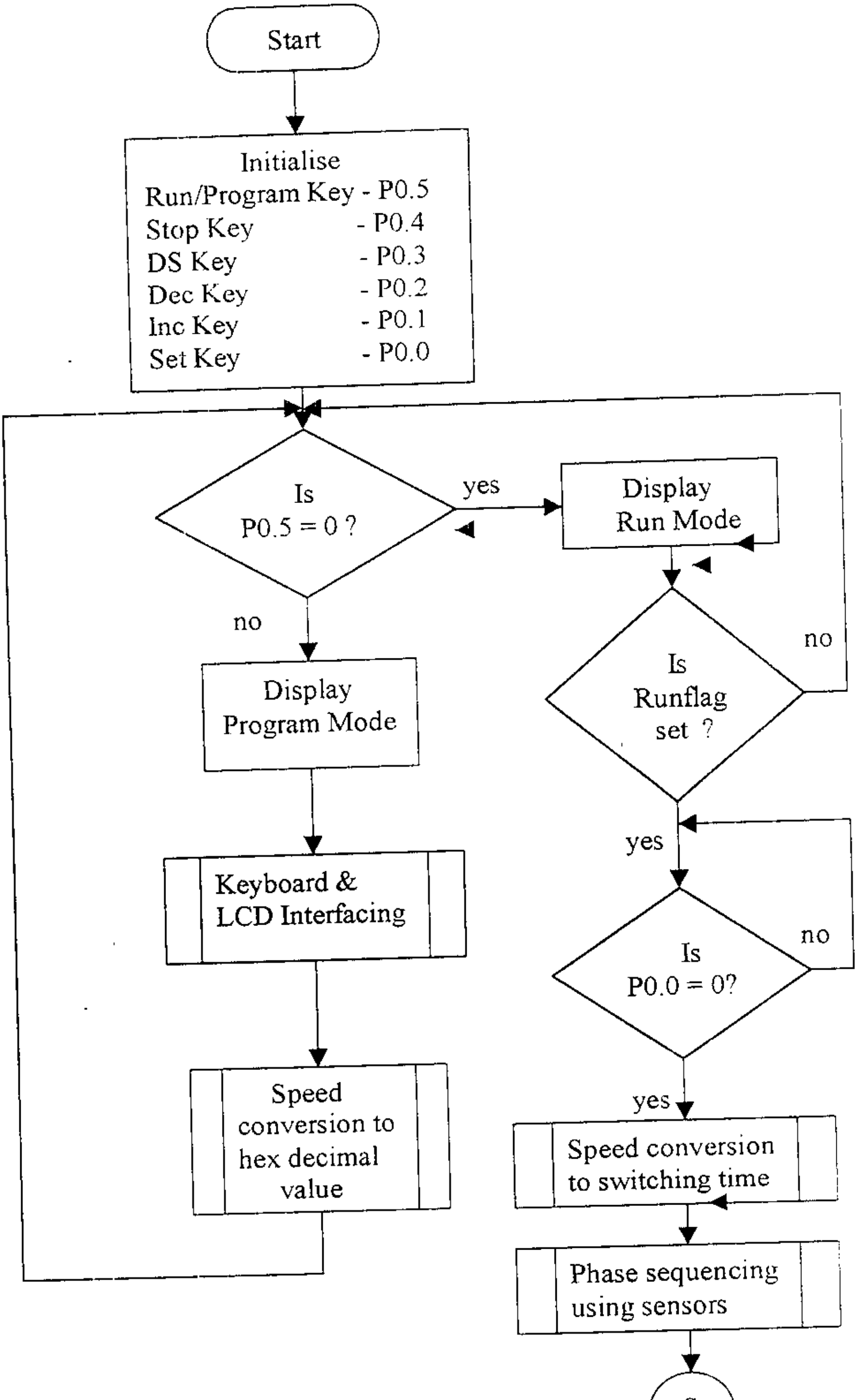
M0 - Mode selector bit.

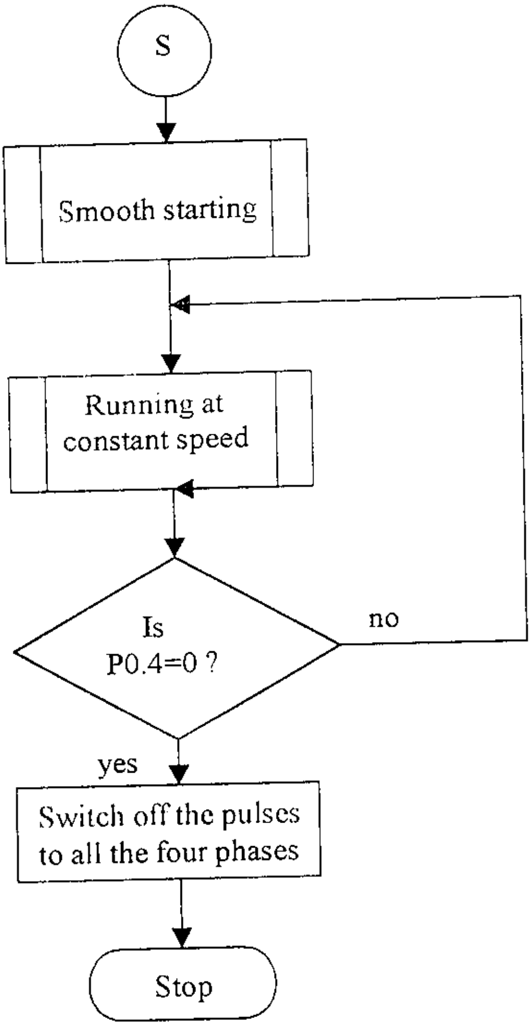
M1	M0	Operating mode
0	0	13-bit counter
0	1	16-bit timer/counter
1	0	8-bit Auto-reload timer/counter
1	1	Split Timer Mode:(Timer 0)TLO is an 8-bit Timer/counter controlled By the standard timer0 control bits ,TH0 is an 8-bit Timer and is controlled by Timer 1 control bits.
1	1	(Timer 1) Timer/Counter 1 stopped.

7.2 GENERAL FLOWCHART



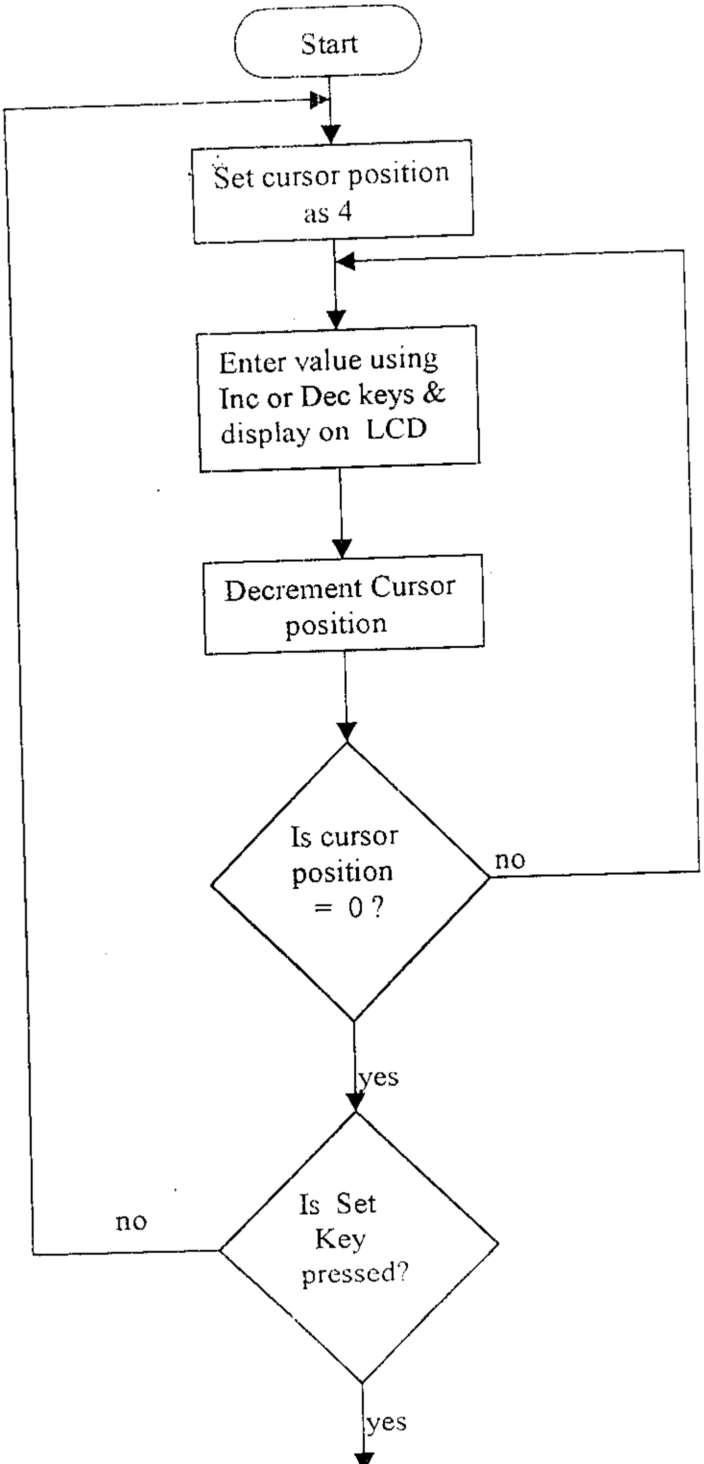
7.3 TECHNICAL FLOWCHART



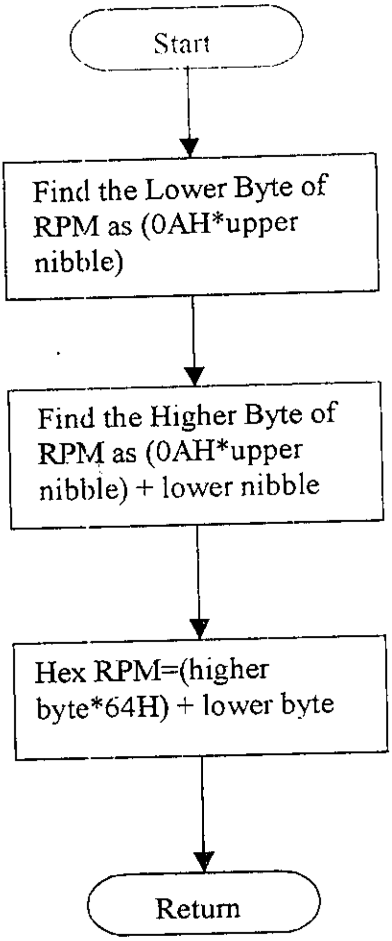

S
Smooth starting
Running at constant speed
Is P0.4=0 ?
no
yes
Switch off the pulses to all the four phases
Stop

ROUTINES

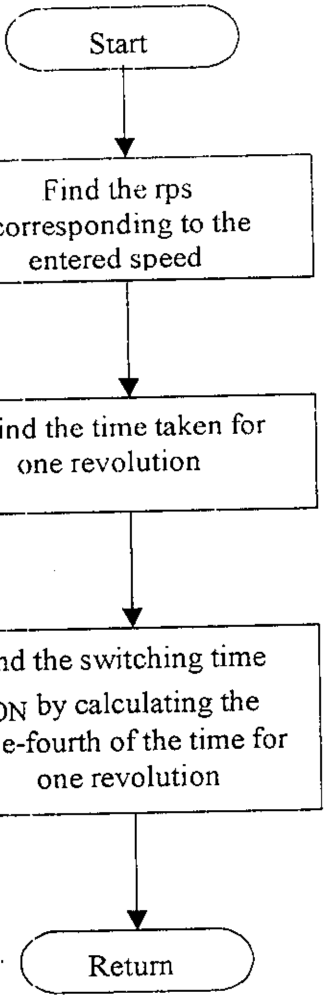
7.3.1 KEYBOARD AND LCD INTERFACING



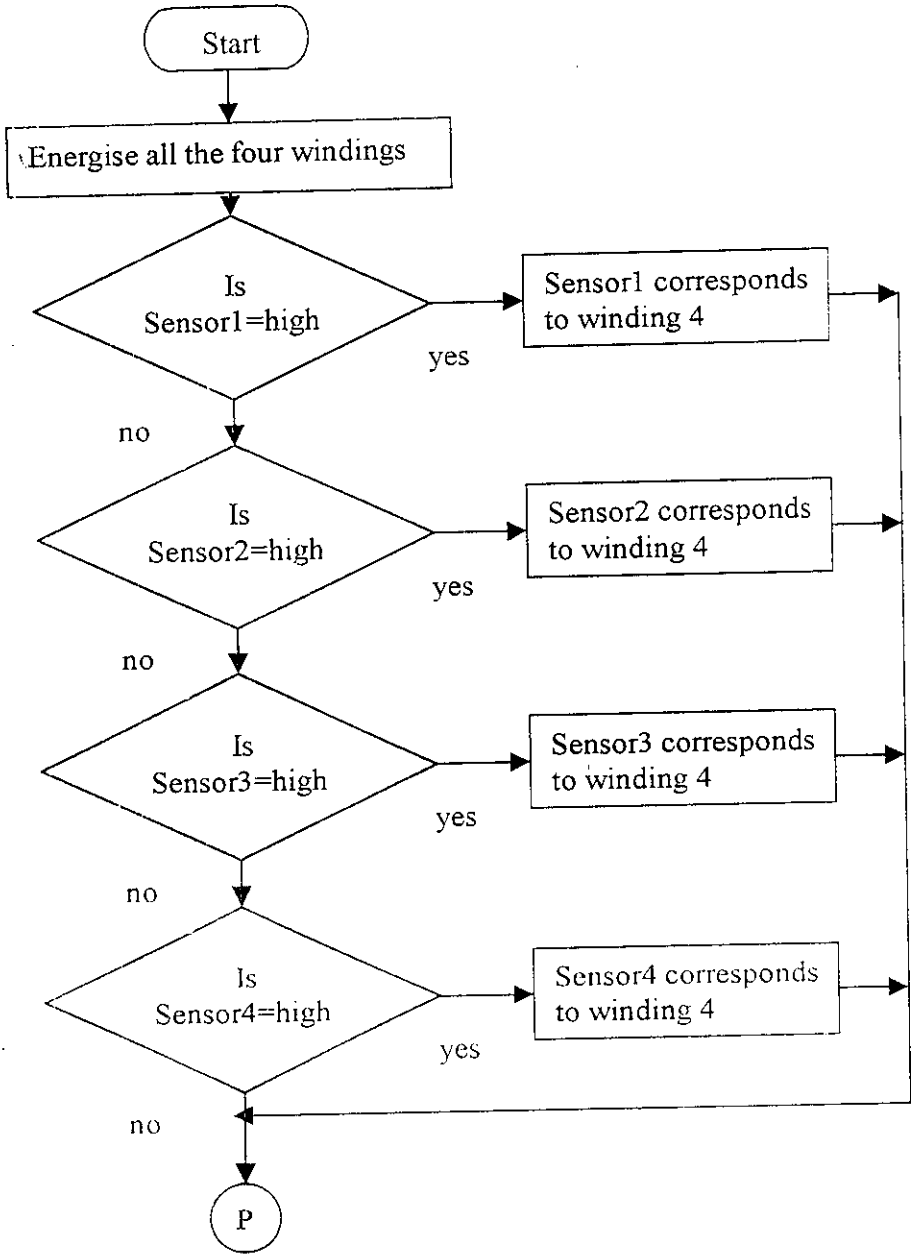
7.3.2 CONVERSION OF SPEED INTO HEXADECIMAL VALUE

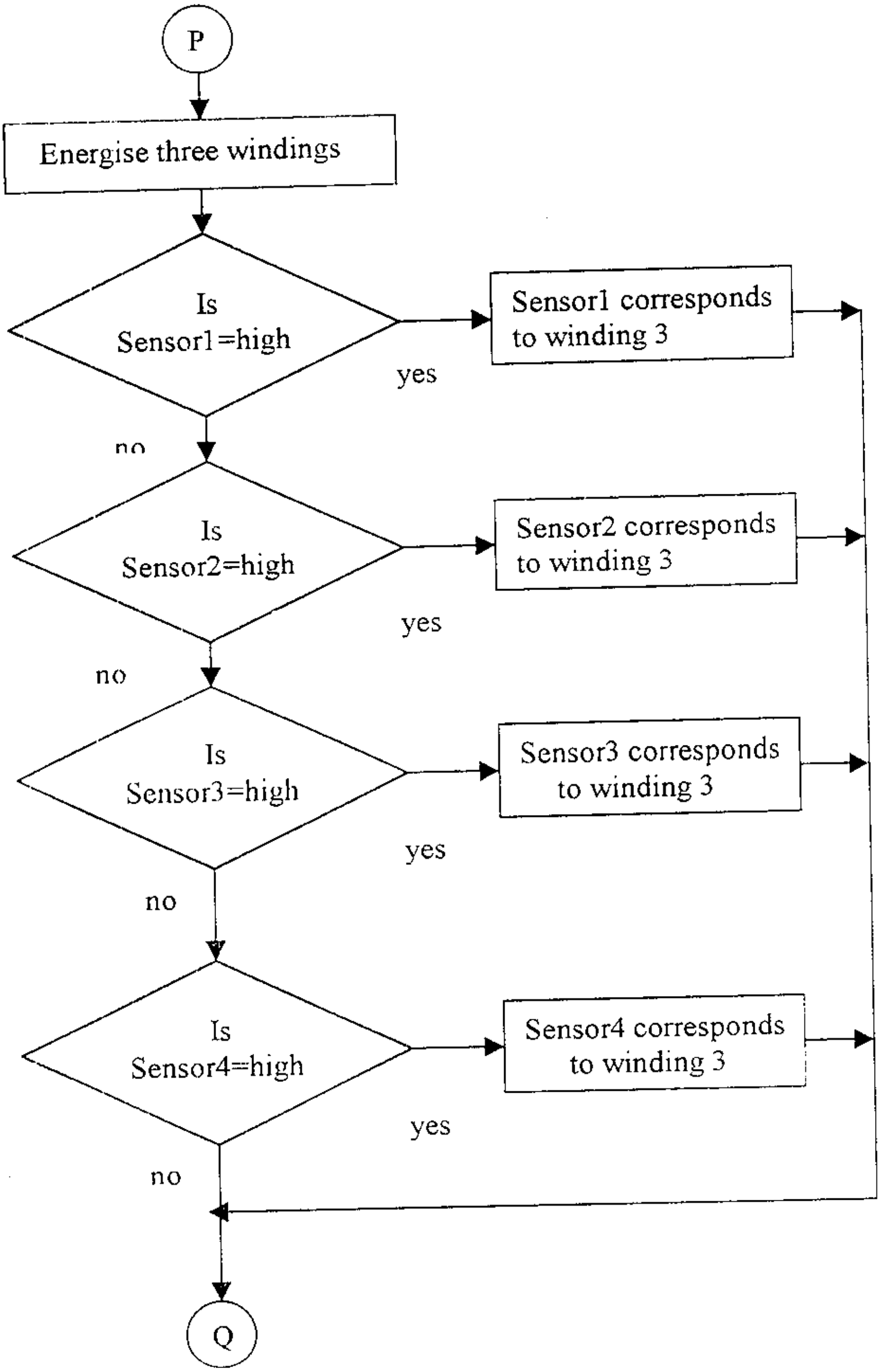


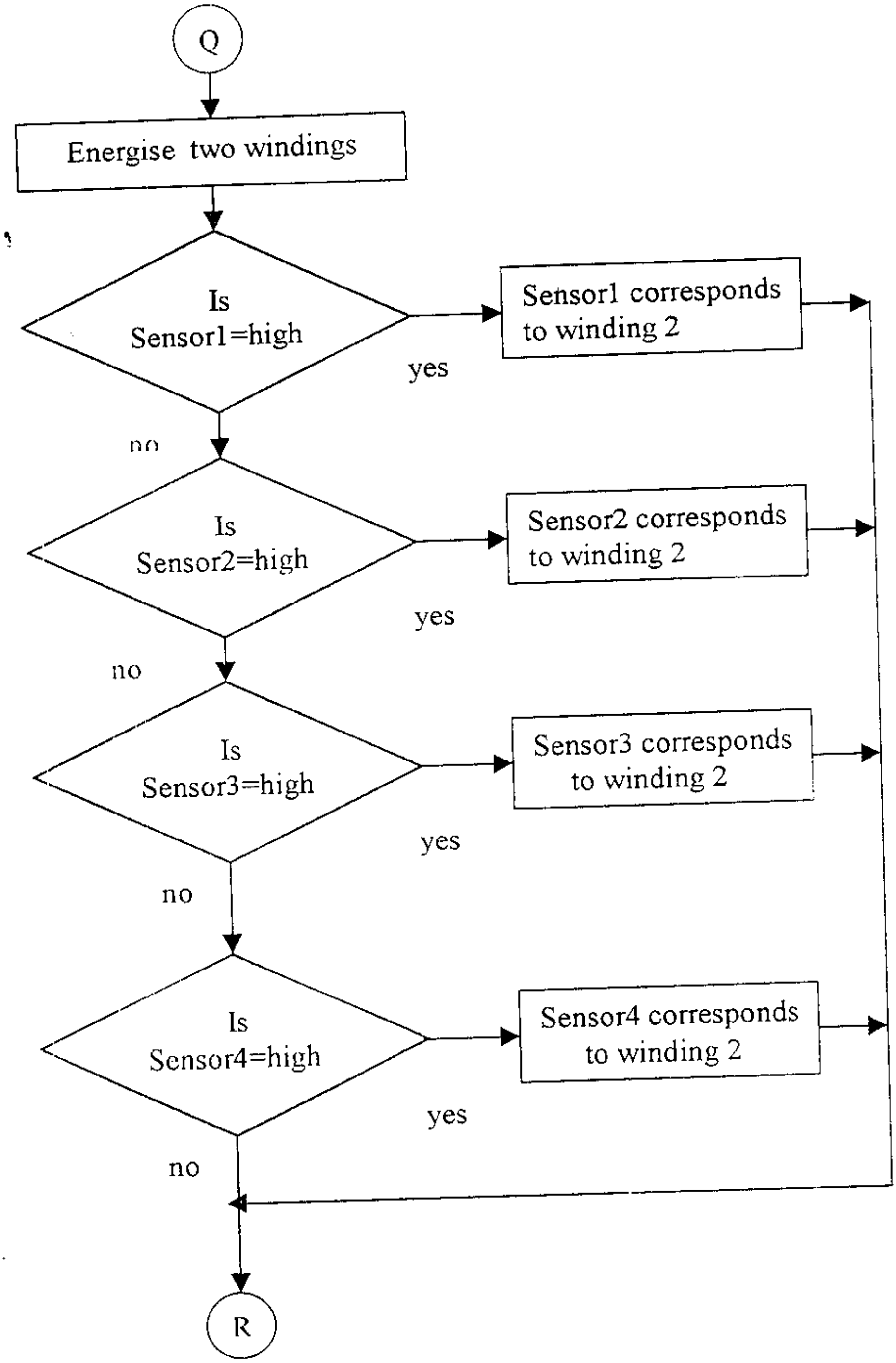
7.3.3 SPEED TO TIME CONVERSION

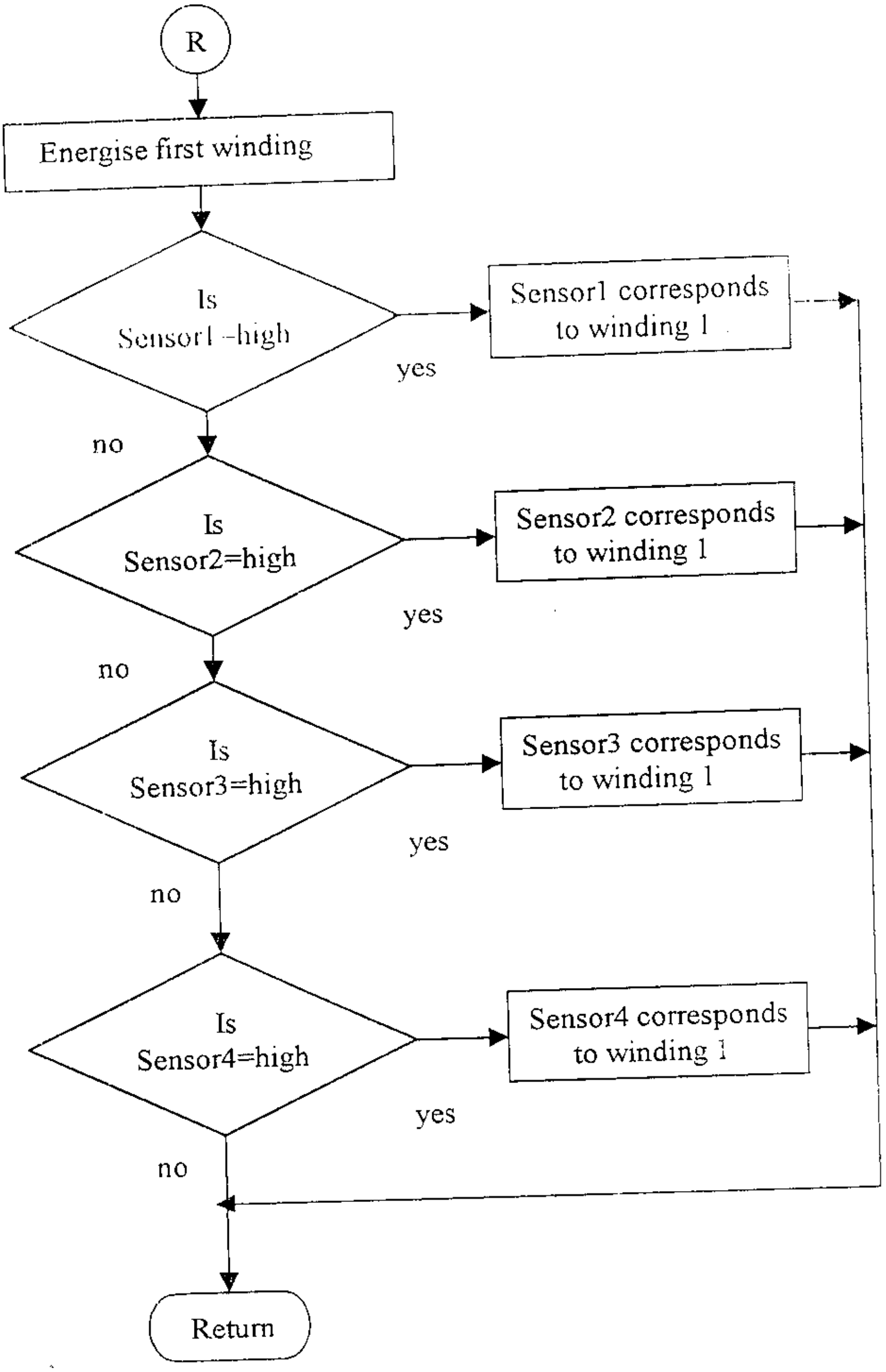


7.3.4 PHASE SEQUENCING USING SENSORS

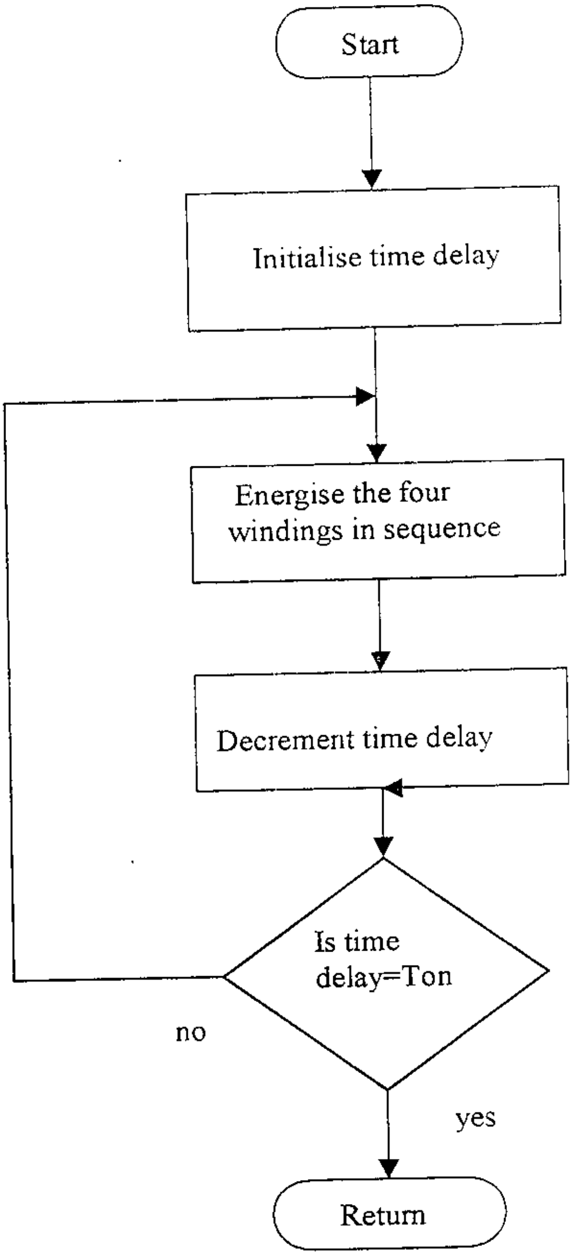



P
Energise three windings
Is
Sensor1=high
yes
Sensor1 corresponds
to winding 3
no
Is
Sensor2=high
yes
Sensor2 corresponds
to winding 3
no
Is
Sensor3=high
yes
Sensor3 corresponds
to winding 3
no
Is
Sensor4=high
yes
Sensor4 corresponds
to winding 3
no
Q

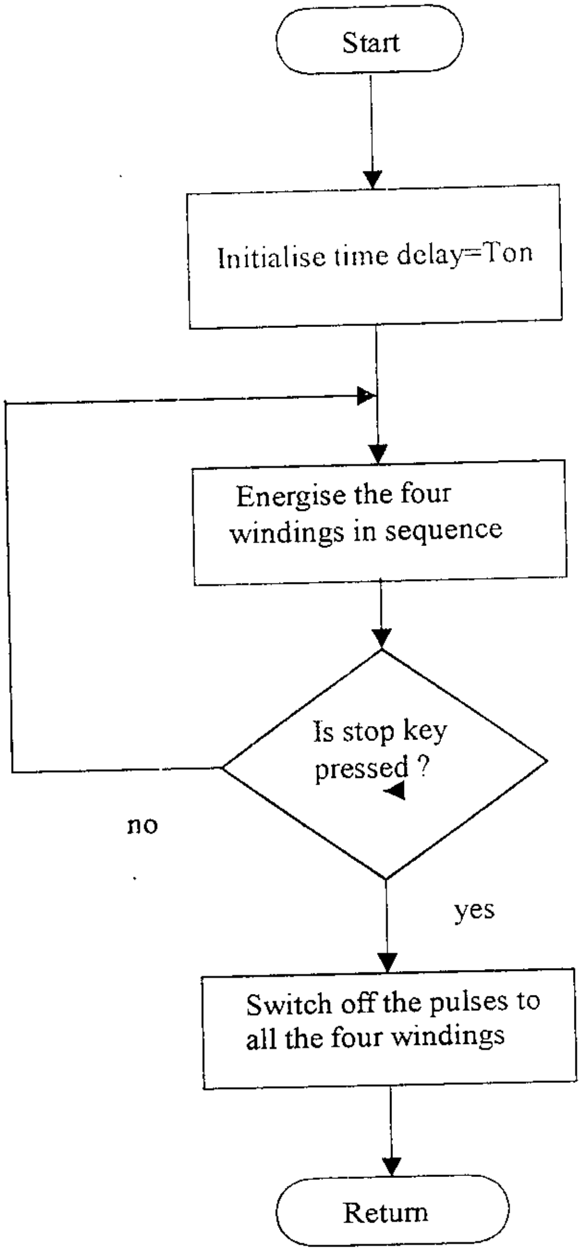

Q
Energise two windings
Is Sensor1=high
yes
Sensor1 corresponds to winding 2
no
Is Sensor2=high
yes
Sensor2 corresponds to winding 2
no
Is Sensor3=high
yes
Sensor3 corresponds to winding 2
no
Is Sensor4=high
yes
Sensor4 corresponds to winding 2
no
R


R
Energise first winding
Is Sensor1 =high
yes
Sensor1 corresponds to winding 1
no
Is Sensor2=high
yes
Sensor2 corresponds to winding 1
no
Is Sensor3=high
yes
Sensor3 corresponds to winding 1
no
Is Sensor4=high
yes
Sensor4 corresponds to winding 1
no
Return

7.3.5 SMOOTH STARTING



7.3.6 RUNNING AT CONSTANT SPEED



Applications

8

APPLICATIONS

Applications where brushless drives are being used today include those not typically requiring very high performance drives, but requiring tough, dependable, continuous duty operation. A significant number of applications on extruders, wire drawers, winders, cranes, cable tensioners, conveyors, pullers, printing presses, roll formers, and other traditional "tough" applications are being done with brushless drives from the major drive system manufacturers.

Brushless DC motors are extensively employed in robots, information devices, home appliances and other areas. Of these small precision motors, the use of the brushless DC motor (or DC brushless motor) is growing at a spectacular pace in many areas including PC peripherals, robots, medical equipment, home appliances (air conditioners, refrigerators, washing machines), and industrial applications (pumps and ventilators). Brushless DC motors are supplanting conventional motors like induction motors, brush DC motors and stepping motors to become the major actuator in mechatronics because of its simple construction, reliability and energy-saving characteristics.

Conclusion & Future Outlook

CONCLUSION & FUTURE OUTLOOK

While there are several options available in choosing the type of drive for variable speed applications, the Brushless D.C. drive offers a precise speed control for both fractional and higher HPs.

In our project, a BLDC motor of 80W, 110V DC is designed to run for speeds ranging from 1000 to 2000 rpm, the rated speed being 1500 rpm. The use of Hall-Effect sensors has helped us achieve good speed control even without feedback.

In future, the current speed can be derived from the position sensor output signals and can be fedback to the microcontroller to be compared with the desired speed in order to achieve more accurate results. Bipolar switching can provide better torque characteristics than that of unipolar switching.

References

REFERENCES

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3. "Design of Brushless Permanent-magnet Motors", J.R. Hendershot and T.J.E. Miller, Magna Physics Publishing and Clarendon Press, 1994.
4. "The 8015 Microcontroller – Architecture, Programming & Applications", Kenneth. J. Ayala, International Thomson Publishing.
5. "The 8051 Microcontroller & Embedded System", Muhammad Ali Mazidi & Janice Gillispie Mazidi.
6. "Customizing the 8051 Programming", Myke Pedko.

Appendix i

```
;***************************************************************************
;                              INITIALISATION
;***************************************************************************

RUN_PROG          EQU      P0.5
STOP              EQU      P0.4
DS                EQU      P0.3
DEC               EQU      P0.2
INC               EQU      P0.1
SET               EQU      P0.0

U_RPM             EQU      62H
L_RPM             EQU      63H
DIGIT1            EQU      64H
DIGIT2            EQU      65H
DIGIT3            EQU      66H
DIGIT4            EQU      67H
W1                EQU      P2.4
W2                EQU      P2.5
W3                EQU      P2.6
W4                EQU      P2.7
RS                EQU      P3.5
RD_WR             EQU      P3.6
EN                EQU      P3.4

RUNFLAG           EQU      20H
EOT               EQU      21H
COM               EQU      22H
DAT               EQU      23H

;***************************************************************************
;                              MAIN PROGRAM
;***************************************************************************
        ORG     0
        JMP     BEGIN
        ORG     00BH
        LJMP    TIMER_ISR0
```

```
BEGIN:
        MOV     P1,#0H
        MOV     P0,#0FFH
        MOV     P3,#0H
        CLR     RUNFLAG
        MOV     DIGIT1,#00H
        MOV     DIGIT2,#00H
        MOV     DIGIT3,#00H
        MOV     DIGIT4,#00H
        JNB     RUN_PROG,RUN
        MOV     R6,#07FH
        LCALL   DELAY5
        LCALL   PROG
        LCALL   CONVERT
WAIT2:
        JB      RUN_PROG,WAIT2
        MOV     R6,#07FH
        LCALL   DELAY5
RUN:
        LCALL   LCDRUN
        JNB     RUNFLAG,BEGIN
WAIT1:
        JB      SET,WAIT1
        MOV     R6,#07FH
        LCALL   DELAY5

        LCALL   SMOOTHSTART
BACK:
        LCALL   REQ_RPM
        JB      STOP,BACK
        CLR     W1
        CLR     W2
        CLR     W3
        CLR     W4
PROG:
        ACALL   LCDPROG
PROG1:
        JB      SET,PROG1
```

```
        MOV       R6,#07FH
        LCALL     DELAY5
RPM:
        ACALL     LCDRPM
RPM1:
          JB        SET,RPM1
          MOV       R6,#07FH
          LCALL     DELAY5
          ACALL     LCDINIT
WAIT55:
          JB        SET,WAIT55
          MOV       R6,#07FH
          LCALL     DELAY5
DS_UNIT:
          ACALL     LDIGIT1
INC1:
          JB        INC,DEC1
          MOV       R6,#07FH
          LCALL     DELAY5
          LCALL     INCR1
          JB        DS,INC1
          MOV       R6,#07FH
          LCALL     DELAY5
          ACALL     DISP_R1
          SJMP      DS_TEN
DEC1:
          JB        DEC,DS_TEN
          MOV       R6,#07FH
          LCALL     DELAY5
          LCALL     DECR1
          JB        DS,INC1
          MOV       R6,#07FH
          LCALL     DELAY5
          ACALL     DISP_R1
DS_TEN:
          JB        DS,INC1
          MOV       R6,#07FH
```

```
        ACALL    LDIGIT2
INC2:
        JB       INC,DEC2
        MOV      R6,#07FH
        LCALL    DELAY5

        LCALL    INCR2
        JB       DS,INC2
        MOV      R6,#07FH
        LCALL    DELAY5

        ACALL    DISP_R2
        SJMP     DS_HUND

DEC2:
        JB       DEC,DS_HUND
        MOV      R6,#07FH
        LCALL    DELAY5

        LCALL    DECR2
        JB       DS,INC2
        MOV      R6,#07FH
        LCALL    DELAY5

        ACALL    DISP_R2
DS_HUND:
        JB       DS,INC2
        MOV      R6,#07FH
        LCALL    DELAY5

        ACALL    LDIGIT3
INC3:
        JB       INC,DEC3
        MOV      R6,#07FH
        LCALL    DELAY5

        LCALL    INCR3
```

```
        LCALL     DECR4
        JB        DS,INC4
        MOV       R6,#07FH
        LCALL     DELAY5

        ACALL     DISP_R4
SETKEY1:
        JNB       DS,DSU
        MOV       R6,#07FH
        LCALL     DELAY5
        JB        SET,INC4
        MOV       R6,#07FH
        LCALL     DELAY5

        CLR       A
        MOV       A,DIGIT2
        RL        A
        RL        A
        RL        A
        RL        A
        ADD       A,DIGIT1
        MOV       L_RPM,A
        CLR       A
        MOV       A,DIGIT4
        RL        A
        RL        A
        RL        A
        RL        A
        ADD       A,DIGIT3
        MOV       U_RPM,A
        RET
 DSU:
        LJMP      DS_UNIT
 CONVERT:
        RET
```

```
        MOV     R6,#07FH
        LCALL   DELAY5

        ACALL    DISP_R3
        SJMP     DS_THOUS
DEC3:
        JB       DEC,DS_THOUS
        MOV     R6,#07FH
        LCALL   DELAY5

        LCALL    DECR3
        JB       DS,INC3
        MOV     R6,#07FH
        LCALL   DELAY5

        ACALL    DISP_R3
DS_THOUS:
        JB       DS,INC3
        MOV     R6,#07FH
        LCALL   DELAY5

        ACALL    LDIGIT4
INC4:
        JB       INC,DEC4
        MOV     R6,#07FH
        LCALL   DELAY5

        LCALL    INCR4
        JB       DS,INC4
        MOV     R6,#07FH
        LCALL   DELAY5

        ACALL    DISP_R4
        SJMP     SETKEY1
DEC4:
        JB       DEC,SETKEY1
        MOV     R6,#07FH
```

```
      MOV      R6,#07FH
      LCALL    DELAYS
      MOV      DPTR,#msg3
      ACALL    MESSAGE
      RET

SMOOTHSTART:

          MOV      QUO,#00H
          MOV      QUO1,#00H
          MOV      R0,#3AH
          MOV      R1,#98H
          MOV      R4,#0D2H
          MOV      R5,#04H
          MOV      A,R4
          MOV      R4,#00H
          CPL      A
          CLR      C
          ADDC     A,#01H
          MOV      R4,A
          CLR      A
          MOV      A,R5
          MOV      R5,#00H
          CPL      A
          MOV      R5,A
          CLR      A
          CLR      C
 LOOP:
          MOV      A,R1
          CLR      C
          ADDC     A,R4
          JNC      LOAD
          INC      R0
 LOAD:
          MOV      R1,A
          PUSH     0E0H
          CLR      A
          MOV      A,R0
```

```
        CLR     C
        ADDC    A,R5
        JNC     OUTER
        INC     QUO
        MOV     R0,A
        PUSH    0E0H
        JMP     LOOP
OUTER:

        MOV     R7,71H
        MOV     20H,QUO
        MOV     A,#42H
        SUBB    A,R7
        JC      MUL_HUN
        MOV     R2,#00H
        MOV     A,#64H
        MOV     B,R7
        MUL     AB
        MOV     74H,A
        MOV     76H,74H
        MOV     75H,B
        MOV     77H,75H
BACK:
        INC     R2
        CJNE    R2,#0AH,READD
LOOP1:
        MOV     A,74H
        ADDC    A,R4
        JNC     LOAD1
        INC     75H
LOAD1:
        MOV     74H,A
        CLR     A
        MOV     A,75H
        CLR     C
        ADDC    A,R5
        JNC     OUTER1
```

```
        MOV     75H,A
        JMP     LOOP1
READD:
        CLR     C
        ADDC    A,74H
        MOV     74H,A
        MOV     A,B
        ADDC    A,75H
        MOV     75H,A
        MOV     A,76H
        MOV     B,77H
        JMP     BACK
OUTER1:
        MOV     41H,QUO1
        ACALL   QUOTENT
ADDQUO1:

        MOV     A,14H
        CLR     C
        ADDC    A,41H
        JNC     LOAD2
        INC     15H
LOAD2:
        MOV     14H,A
        ACALL   SUBT
        ACALL   SUBT1
        MOV     R2,#00H
        ACALL   DIV4
        LJMP    MAIN2
READD1:
        CLR     C
        ADDC    A,12H
        MOV     12H,A
        MOV     A,B
        ADDC    A,13H
        MOV     13H,A
        MOV     A,14H
```

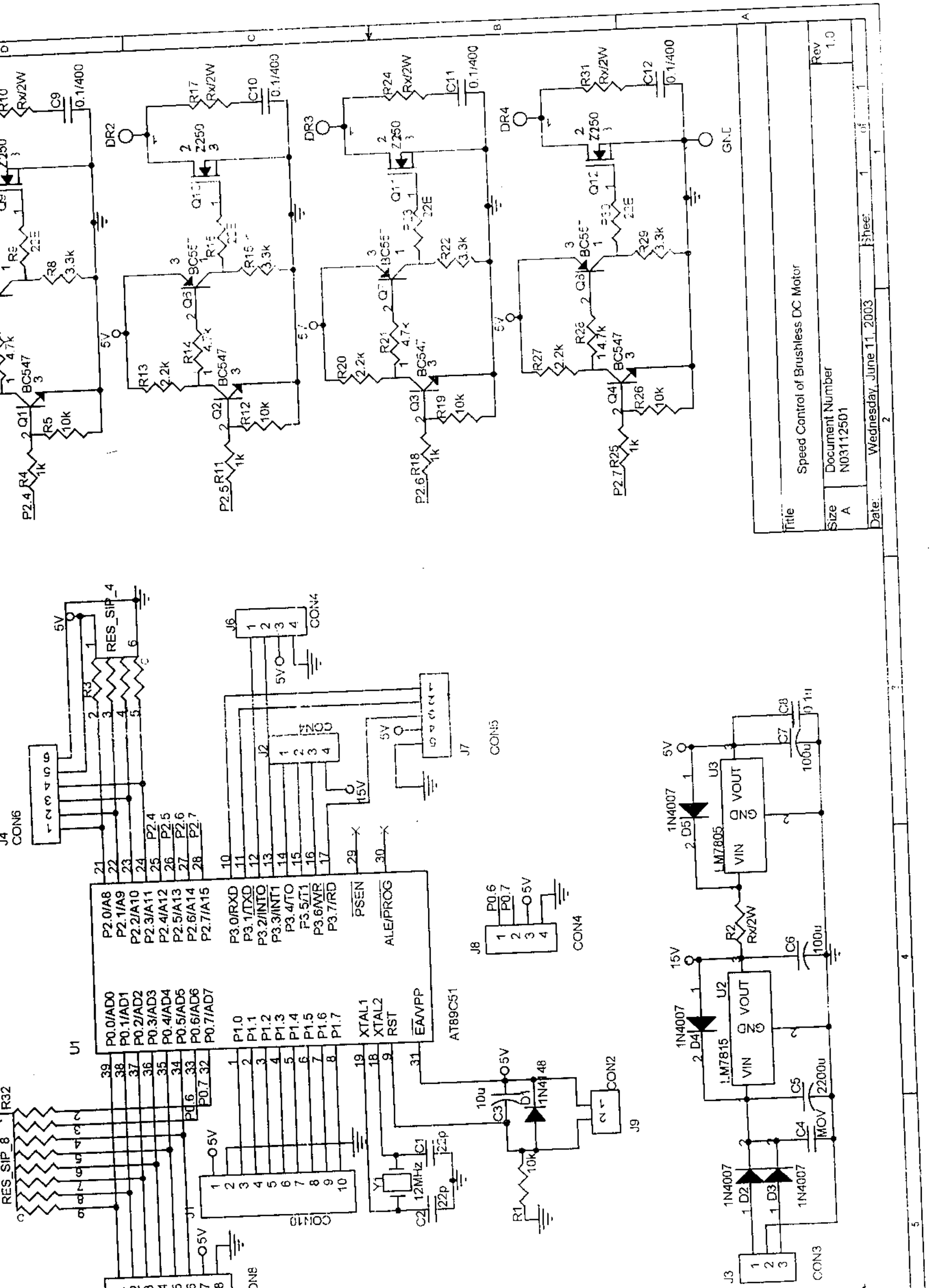
```
        JMP     BACK1
MUL_HUN:
        MOV     A,#64H
        MOV     B,R7
        MUL     AB
        MOV     74H,A
        MOV     75H,B
 LOOP3:
        MOV     A,74H
        CLR     C
        ADDC    A,R4
        JNC     LOAD3
        INC     75H
 LOAD3:
        MOV     74H,A
        CLR     A
        MOV     A,75H
        CLR     C
        ADDC    A,R5
        JNC     OUTER2
        INC     QUO1
        MOV     75H,A
        JMP     LOOP3
 OUTER2:
        MOV     30H,QUO1
        CLR     A
        MOV     A,30H
        MOV     B,#0AH
        MUL     AB
        MOV     31H,A
        MOV     32H,B
        ACALL   QUOTENT
        MOV     A,14H
        CLR     C
        ADDC    A,31H
        JNC     LOAD4
        INC     15H
```

```
        MOV     14H,A
        CLR     A
        MOV     A,15H
        CLR     C
        ADDC    A,32H
        MOV     15H,A
        ACALL   SUBT
        ACALL   SUBT1
        MOV     R2,#00H
        ACALL   DIV4
        LJMP    MAIN2
        MOV     14H,12H
        MOV     13H,B
        MOV     15H,13H
BACK1:
        INC     R0
        CJNE    R0,#0AH,READD1
        MOV     14H,12H
        MOV     15H,13H
        RET
SUBT:
        CLR     A
        MOV     A,#0FFH
        SUBB    A,14H
        MOV     14H,A
        CLR     A
        MOV     A,#0FFH

        SUBB    A,15H
        MOV     15H,A
        RET
SUBT1:
        MOV     A,14H
        CLR     C
        SUBB    A,#36H
        MOV     14H,A
        JNC     SUBT2
```

```
SUBT2:
        CLR     A
        MOV     A,15H
        CLR     C
        SUBB    A,#80H
        MOV     15H,A
        RET
DIV4:
        MOV     A,15H
        CLR     C
        RRC     A
        MOV     15H,A
        JC      OVER
        CLR     A
        MOV     A,14H
        CLR     C
        RRC     A
        MOV     14H,A
        INC     R2
        CJNE    R2,#04H,DIV4
        RET
OVER:

        CLR     A
        MOV     A,14H
        RR      A
        ORL     A,#80H
        MOV     14H,A
        INC     R2
        CJNE    R2,#03H,DIV4
        RET

REQ_RPM:
        RET
LDIGIT1:
        MOV     DPTR,#msg4
        ACALL   MESSAGE
```

```
LDIGIT2:
        MOV     DPTR,#msg5
        ACALL   MESSAGE
        RET
LDIGIT3:
        MOV     DPTR,#msg6
        ACALL   MESSAGE
        RET
LDIGIT4:
        MOV     DPTR,#msg7
        ACALL   MESSAGE
        RET
DELAYS1:
        MOV     R4,#02H
STAY1:
        DJNZ    R4,STAY1
        DJNZ    R6,DELAYS1
        RET

DISPLAY:

        MOV     P1,A
        SETB    RS
        CLR     RD_WR
        SETB    EN
        NOP
        NOP
        CLR     EN
        MOV     R6,#07H
        ACALL   DELAYS
        RET

msg1:
        DB COM,30H,30H,30H,38H,14H,0EH,06H,01H,DAT,"PROGRAM",0A0H,"MODE",EOT
msg2:
        DB COM,30H,30H,30H,38H,14H,0EH,06H,01H,DAT,"ENTER",0A0H,"RPM",EOT
msg3:
        DB COM,30H,30H,30H,38H,14H,0EH,06H,01H,DAT,"RUN",0A0H,"MODE",EOT
```

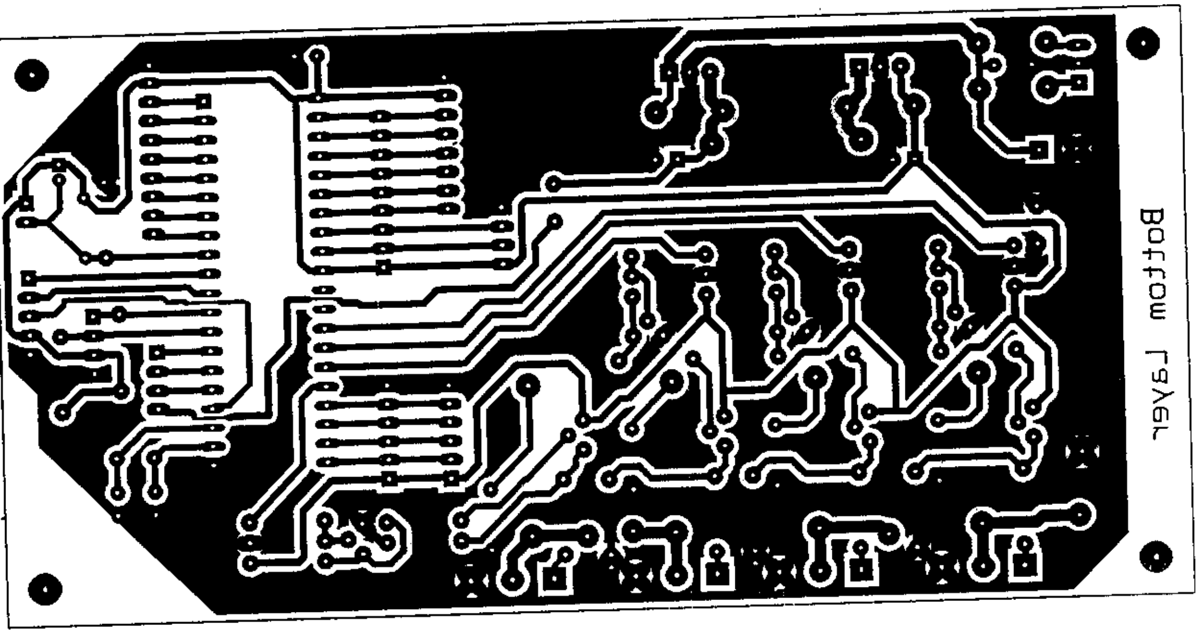
```
msg4:
        DB  COM,30H,08H,14H,0FH,06H,02H,86H,EOT
msg5:
        DB  COM,30H,08H,14H,0FH,06H,02H,85H,EOT
msg6:
        DB  COM,30H,08H,14H,0FH,06H,02H,84H,EOT
msg7:
        DB  COM,30H,08H,14H,0FH,06H,02H,83H,EOT
initial:
        DB  COM,30H,08,10H,0CH,06H,01H,86H,EOT


        END
```



Title
Speed Control of Brushless DC Motor

Size A
Document Number N03112501
Rev 1.0

Date: Wednesday, June 11, 2003
Sheet 1 of 1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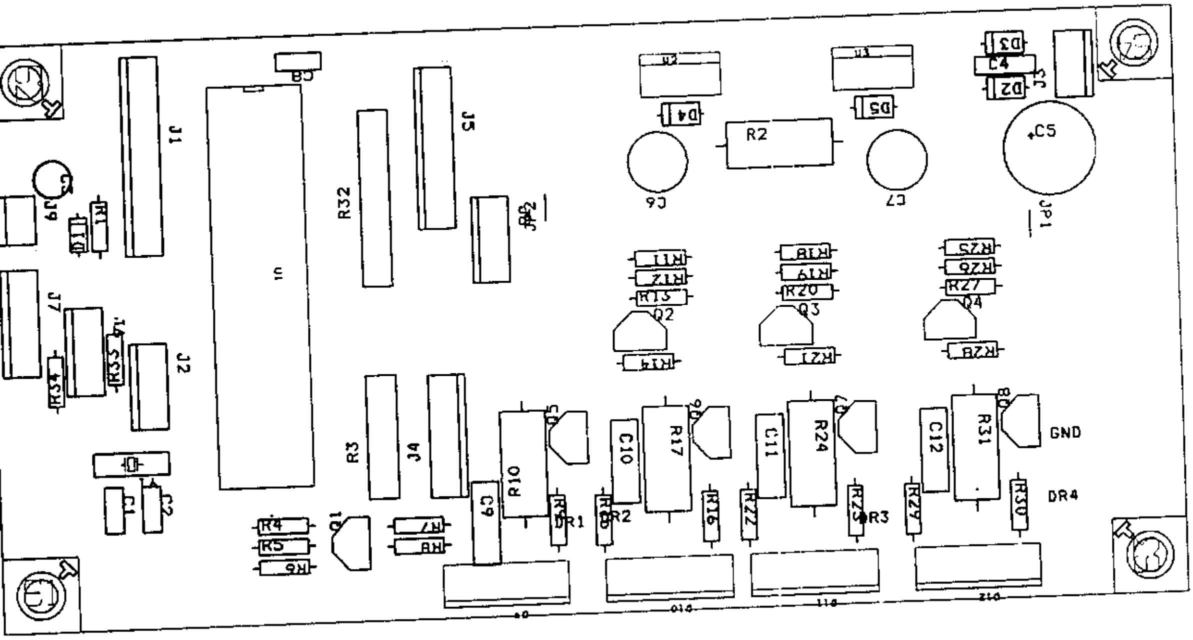
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J3
C5
JP1
J9
R1
D1
J7
J6
R33
R34
J2
R11
R12
R13
Q2
R14
R18
R19
R20
Q3
R21
R25
R26
R27
Q4
R28
C1
C2
R4
R5
R6
Q1
R7
R8
R3
J4
C9
R10
Q5
R9
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C10
R17
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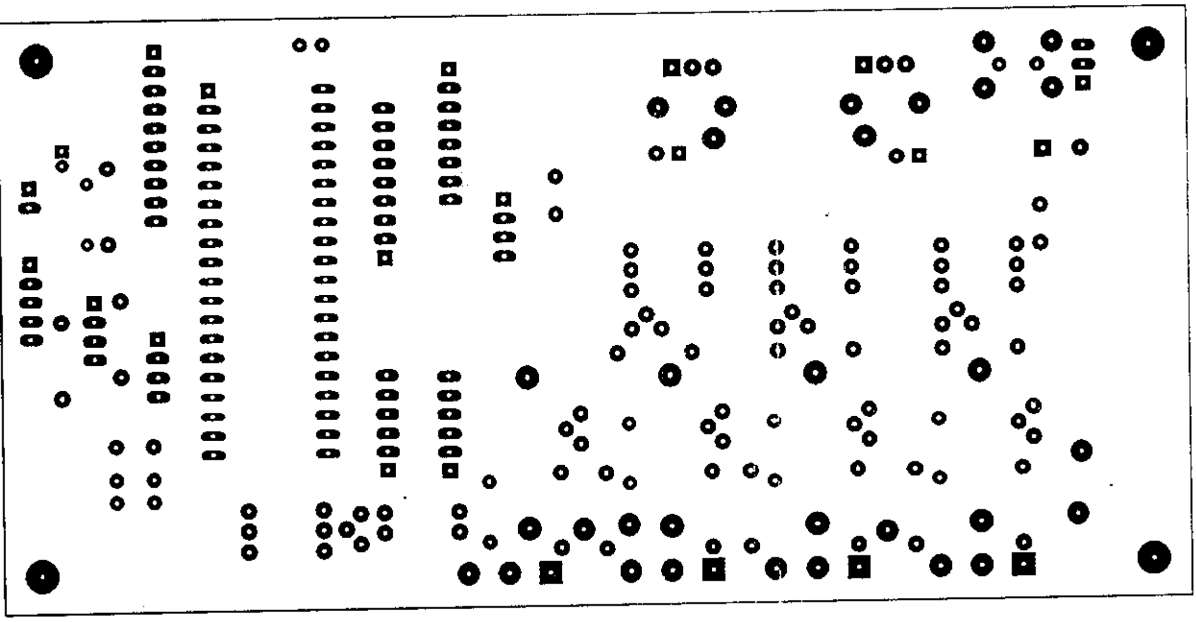
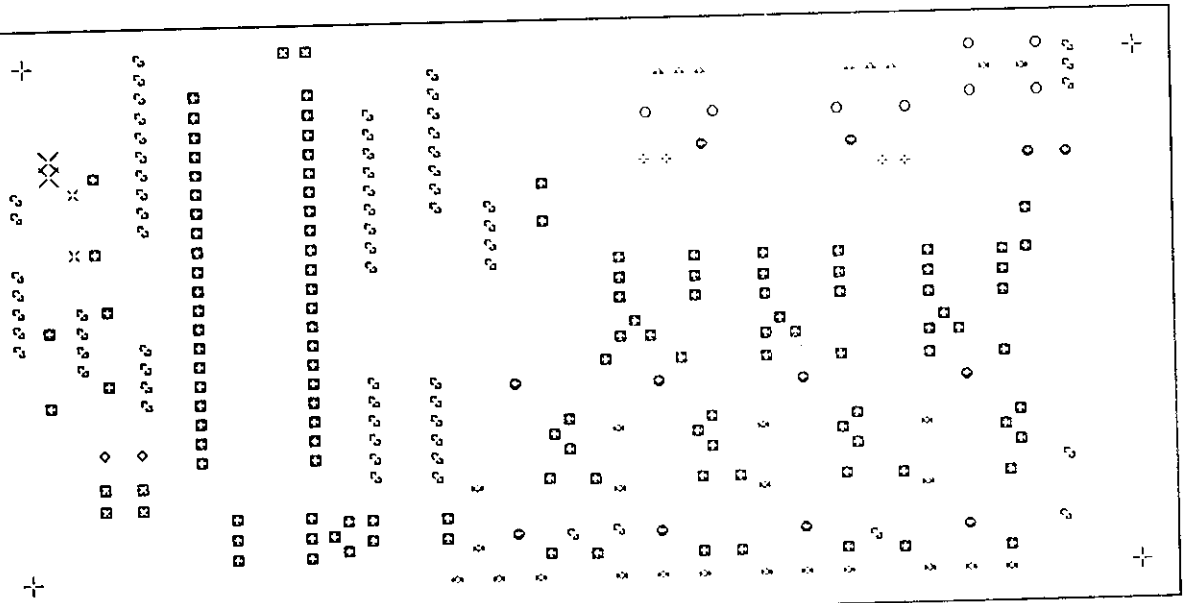
R29
R30
DR4





DRILL CHART

SYM	DIAM	TOL	QTY	NOTE
╳	0.700 mm		2	
×	0.799 mm		2	
+	0.800 mm		4	
◇	0.899 mm		2	
▣	0.900 mm		122	
∞	0.965 mm		10	
⊞	0.965 mm		6	
⧉	1.000 mm		66	
⊖	1.000 mm		12	
○	1.200 mm		8	
▲	1.295 mm		6	
∞	1.599 mm		12	
┼	3.499 mm		4	
TOTAL			256	

Appendix ii

Properties of Alnico Magnets

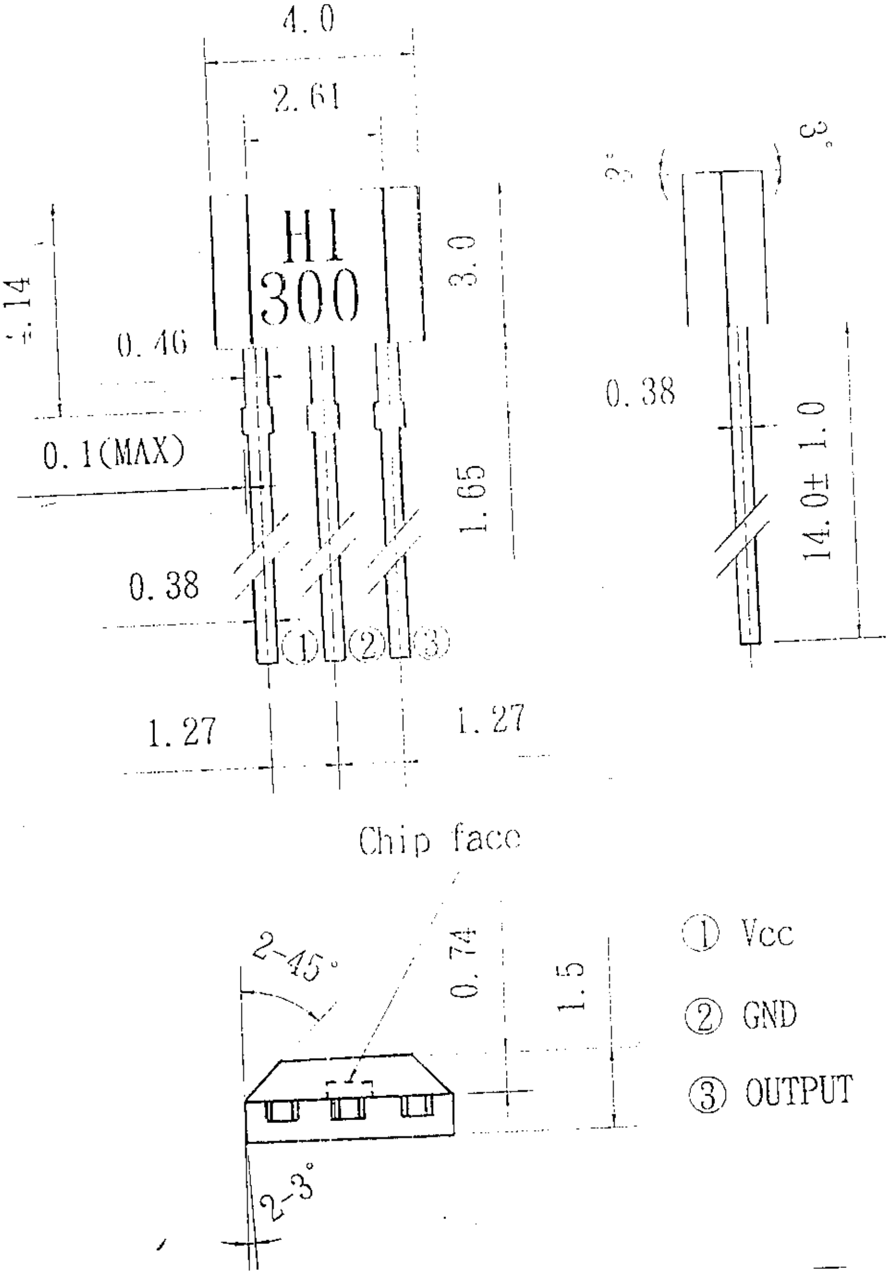
Magnetic Properties

Grade	B_r (Gauss)	H_c (Oersteds)	H_{ci} (Oersteds)	BH_{max} (MGOe)	Max. Op. Temp. (°C)	Relative Cost by Wt.
5 Cast	12,500	640	640	5.5	540	15
5-7 Cast	13,500	740	740	7.5	540	30
6 Cast	10,500	780	800	3.9	540	20
8 Cast	8,300	1,650	1,650	5.5	540	18
2 Sintered	6,600	550	550	1.4	540	8
5 Sintered	10,800	600	600	3.8	540	10
8 Sintered	7,000	1,900	1,900	5.0	540	10

Material and Grade	Reversible Temperature Cofficient of Br (% Change / °C)			Curie Temperature		Max. Service Temperature	
	Near Br	Near Max. Energy Prod.	Near Hc	°C	°F	°C	°F
Alnico 2	-0.03	-0.02	-0.02	810	1490	450	840
Alnico 5	-0.02	-0.015	-0.01	860	1580	525	975
Alnico 6	-0.02	-0.015	-0.03	860	1580	525	975
Alnico 8	-0.025	-0.01	-0.01	860	1580	550	1020

Material and Grade	Density		Tensile Strength psi	Transverse Modalus of Rupture	Hardness (Rockwell C)	Coefficient Of Thermal Expansion (Inches x10^{-6} Per°C)	Electrical Resistivity(Ohm-cm x 10^{-6} at 20 °C
	g/cm^3	lbs/in^3					
Alnico 5, Cast	7.3	0.264	5,400	10,500	50	11.4	47
Alnico 6, Cast	7.3	0.265	23,000	45,000	50	11.4	50
Alnico 8, Cast	7.3	0.262	10,000	30,000	55	11	53
Alnico 2, Sintered	6.8	0.246	65,000	70,000	45	12.4	68
Alnico 5	[illegible]	[illegible]	50,000	55,000	45	11.3	50

CKAGE DIMENSIONS:



FEATURES:

3V to 20V operation.
No need for reverse voltage.
High reliability.
Small size.
Output compatible with all digital logic families.

APPLICATIONS:

CAL CHARACTERISTICS CURVES:

Fig. 1 Supply Current V.S. Supply Voltage

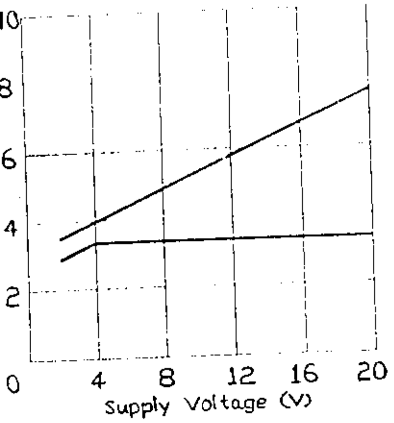


Fig. 2 Output Low Voltage V.S. Supply Voltage

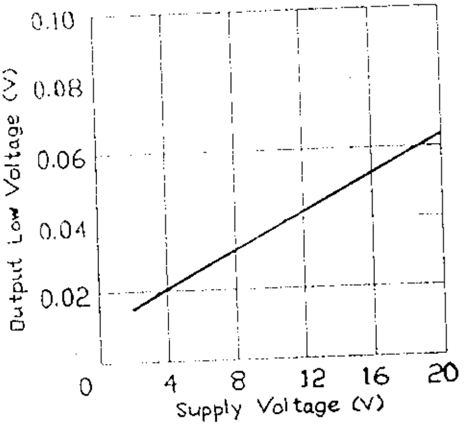


Fig. 3 Switch Points (Bop,Brp) V.S. Supply Voltage

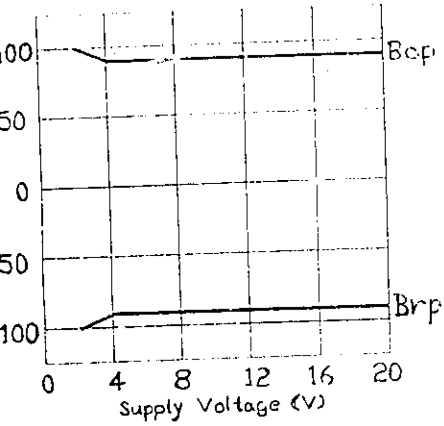


Fig. 4 Switch Points V.S. Ambient Temperature

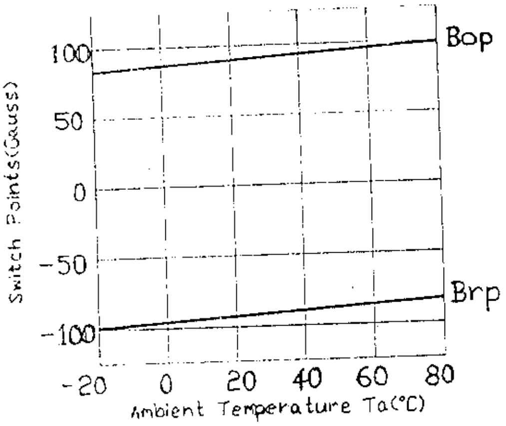


Fig. 5 Supply Current V.S. Ambient Temperature

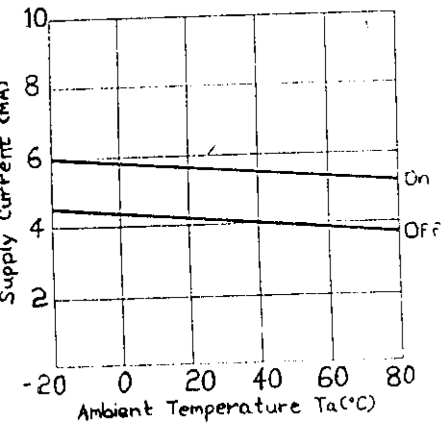
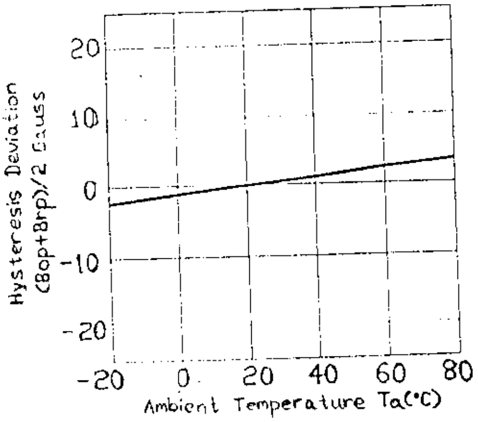


Fig. 6 Hysteresis Deviation V.S. Ambient Temperature



(Ta=25℃)

OLUTE MAXIMUM RATINGS:

PARAMTER	SYMBOL	RATING	UNIT	CONDITION
ly Voltage	V_{cc}	20	V	-
ly Current	I_{cc}	8	mA	-
ut Current	I_{OUT}	20	mA	-
imum Power ipation	P_D	100	mW	-
rating Ambient nperature	T_A	-20~+85	℃	-
age Temperature	T_{STG}	-40~+120	℃	-
dering Temperature	T_{SOL}	260	℃	1/16 inch from body for 5 seconds

(Ta=25℃)

LECTICAL CHARACTERISTICS:

ARAMETER	SYMBOL	MIN.	TYP.	MAX.	UNIT	CONDITION
pply Voltage	V_{cc}	3	-	20	V	Operating
tput Saturation ltage	V_{SAT}	-	-	0.2	V	I_{OUT}=5mA,B>Bop
pply Current	I_{cc}	-	3.5	6	mA	Operating
tput Leakage rrent	I_{LEAK}	-	0.5	2	μA	V_{OUT}=20V,B>Brp
tput Rise Time	t_r	-	0.4	-	μS	V_{cc}=12V, R_L=4.7kΩ, C_L=20pF
tput Rise Time	t_r	-	0.4	-	μS	

(Ta=25℃)

Unit :Gauss

ANKING:

ondition:Vcc=20V

Bin Number	Bin 1	Bin 2	Bin 3	Bin 4
Min	1	55	85	125
Max	70	100	140	200

8-bit Microcontroller with 4K Bytes Flash

AT89C51

Not Recommended for New Designs. Use AT89S51.

tures

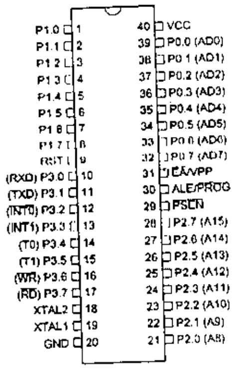
- mpatible with MCS-51™ Products
- Bytes of In-System Reprogrammable Flash Memory
  - – Endurance: 1,000 Write/Erase Cycles
- lly Static Operation: 0 Hz to 24 MHz
- ree-level Program Memory Lock
- 8 x 8-bit Internal RAM
- Programmable I/O Lines
- vo 16-bit Timer/Counters
- x Interrupt Sources
- rogrammable Serial Channel
- ow-power Idle and Power-down Modes

escription

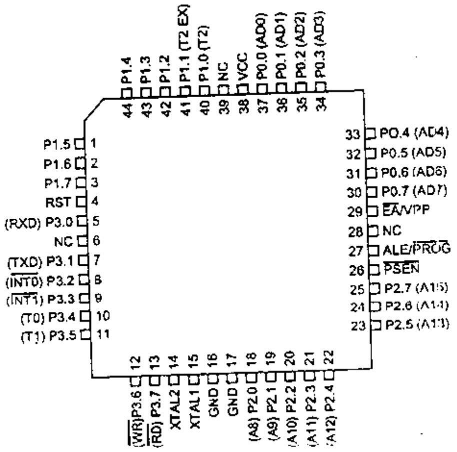
e AT89C51 is a low-power, high-performance CMOS 8-bit microcomputer with 4K
es of Flash programmable and erasable read only memory (PEROM). The device
manufactured using Atmel's high-density nonvolatile memory technology and is
mpatible with the industry-standard MCS-51 instruction set and pinout. The on-chip
sh allows the program memory to be reprogrammed in-system or by a conven-
nal nonvolatile memory programmer. By combining a versatile 8-bit CPU with Flash
a monolithic chip, the Atmel AT89C51 is a powerful microcomputer which provides
ighly-flexible and cost-effective solution to many embedded control applications.

n Configurations

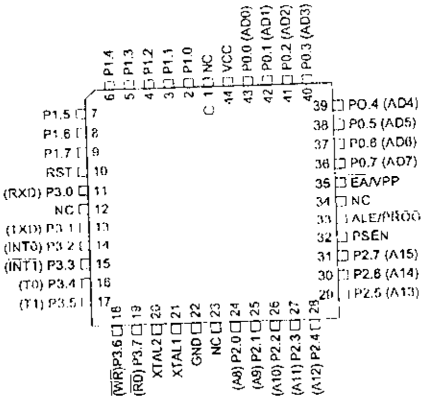
PDIP



PQFP/TQFP

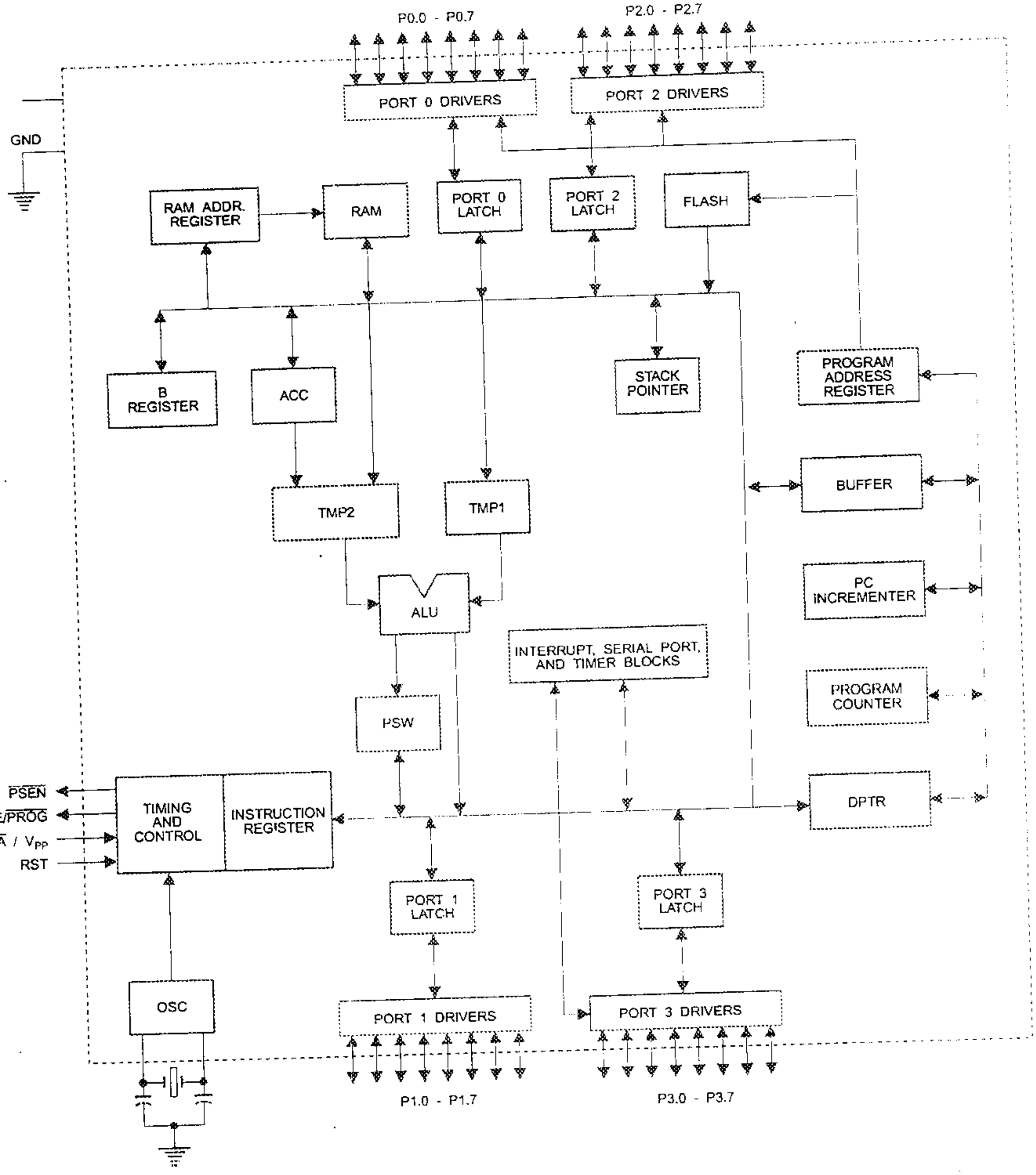


PLCC



Rev. 0265G–02/00

ck Diagram


P0.0 - P0.7
P2.0 - P2.7
PORT 0 DRIVERS
PORT 2 DRIVERS
GND
RAM ADDR. REGISTER
RAM
PORT 0 LATCH
PORT 2 LATCH
FLASH
B REGISTER
ACC
STACK POINTER
PROGRAM ADDRESS REGISTER
BUFFER
TMP2
TMP1
ALU
PC INCREMENTER
INTERRUPT, SERIAL PORT, AND TIMER BLOCKS
PROGRAM COUNTER
PSW
PSEN
E/PROG
A / V_PP
RST
TIMING AND CONTROL
INSTRUCTION REGISTER
DPTR
PORT 1 LATCH
PORT 3 LATCH
OSC
PORT 1 DRIVERS
PORT 3 DRIVERS
P1.0 - P1.7
P3.0 - P3.7

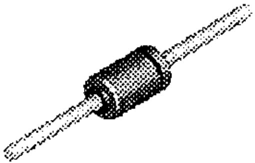
FAIRCHILD
SEMICONDUCTOR TM

Discrete POWER & Signal Technologies

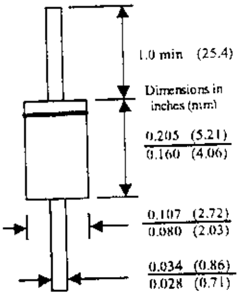
1N4001 - 1N4007

Features

- Low forward voltage drop.
- High surge current capability.



DO-41
COLOR BAND DENOTES CATHODE



1.0 Ampere General Purpose Rectifiers

Absolute Maximum Ratings*

T_A = 25°C unless otherwise noted

Symbol	Parameter	Value	Units
I_O	Average Rectified Current .375 " lead length @ T_A = 75°C	1.0	A
$I_{F(surge)}$	Peak Forward Surge Current 8.3 ms single half-sine-wave Superimposed on rated load (JEDEC method)	30	A
P_D	Total Device Dissipation Derate above 25°C	2.5 20	W mW/°C
$R_{\theta JA}$	Thermal Resistance, Junction to Ambient	50	°C/W
T_{stg}	Storage Temperature Range	-55 to +175	°C
T_J	Operating Junction Temperature	-55 to +150	°C

*These ratings are limiting values above which the serviceability of any semiconductor device may be impaired.

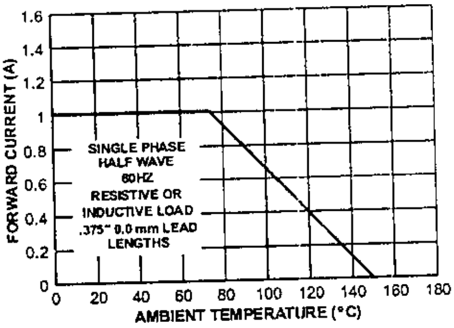
Electrical Characteristics

T_A = 25°C unless otherwise noted

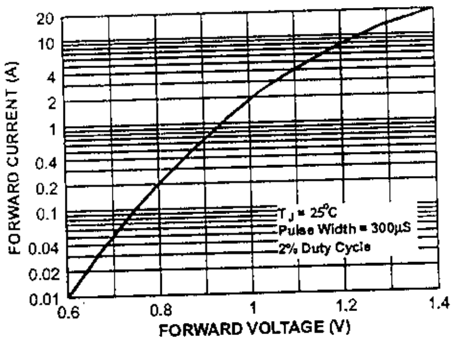
Parameter	Device							Units
	4001	4002	4003	4004	4005	4006	4007	
Peak Repetitive Reverse Voltage	50	100	200	400	600	800	1000	V
Maximum RMS Voltage	35	70	140	280	420	560	700	V
DC Reverse Voltage (Rated V_R)	50	100	200	400	600	800	1000	V
Maximum Reverse Current @ rated V_R T_A = 25°C T_A = 100°C	5.0 500							µA µA
Maximum Forward Voltage @ 1.0 A	1.1							V
Maximum Full Load Reverse Current, Full Cycle T_A = 75°C	30							µA
Typical Junction Capacitance V_R = 4.0 V, f = 1.0 MHz	15							pF

Typical Characteristics

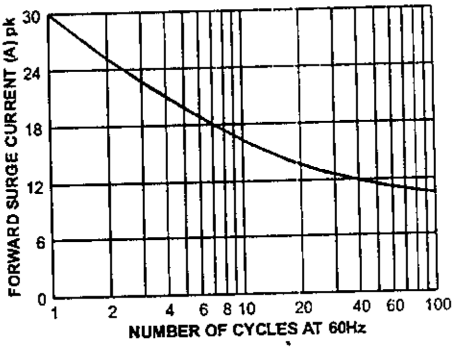
Forward Current Derating Curve



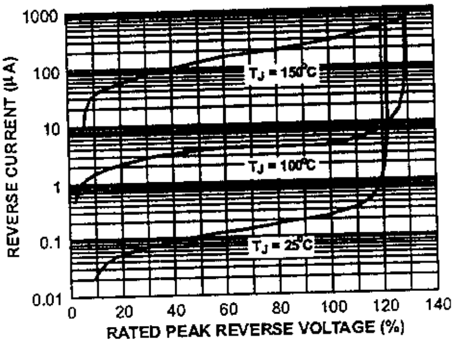
Forward Characteristics



Non-Repetitive Surge Current



Reverse Characteristics



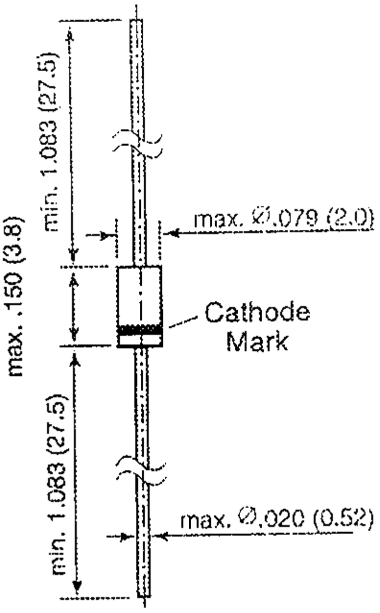
1N5225 thru 1N5267

Vishay Semiconductors
formerly General Semiconductor

Zener Diodes

Zener Voltage Range 3.0 to 75V
Power Dissipation 500mW

DO-204AH
(DO-35 Glass)



Dimensions in inches and (millimeters)

Features

- Silicon Planar Power Zener Diodes.
- Standard Zener voltage tolerance is ±5% with a "B" suffix. Other tolerances are available upon request.
- These diodes are also available in MiniMELF case with the type designation ZMM5225 ... ZMM5267, SOT-23 case with the type designation MMBZ5265 ... MMBZ5267 and SOD-23 case with the types designation MMSZ5225 ... MMSZ5267

Mechanical Data

Case: DO-35 Glass Case

Weight: approx. 0.13g

Packaging codes/options:
D7/10K per 13" reel, (52mm tape), 20K/box
D8/10K per Ammo tape (52mm tape), 20K/box

Maximum Ratings and Thermal Characteristics (T$_A$ = 25°C unless otherwise noted)

Parameter	Symbol	Value	Unit
Zener Current (see Table "Characteristics")			
Power Dissipation at T_{amb} = 75°C	P_{tot}	500$^{(1)}$	mW
Thermal Resistance Junction to Ambient Air	$R_{\theta JA}$	300$^{(1)}$	°C/W
Maximum Junction Temperature	T_J	175	°C
Storage Temperature Range	T_S	–65 to +175	°C

Note:
1) Valid provided that leads at a distance of 10mm from case are kept at ambient temperature.

February 2000

National Semiconductor

LM340/LM78MXX Series
3-Terminal Positive Regulators

General Description

The LM140/LM340A/LM340/LM7800C monolithic 3-terminal positive voltage regulators employ internal current-limiting, thermal shutdown and safe-area compensation, making them essentially indestructible. If adequate heat sinking is provided, they can deliver over 1.0A output current. They are intended as fixed voltage regulators in a wide range of applications including local (on-card) regulation for elimination of noise and distribution problems associated with single-point regulation. In addition to use as fixed voltage regulators, these devices can be used with external components to obtain adjustable output voltages and currents.

Considerable effort was expended to make the entire series of regulators easy to use and minimize the number of external components. It is not necessary to bypass the output, although this does improve transient response. Input bypassing is needed only if the regulator is located far from the filter capacitor of the power supply.

The 5V, 12V, and 15V regulator options are available in the steel TO-3 power package. The LM340A/LM340/LM7800C series is available in the TO-220 plastic power package, and the LM340-5.0 is available in the SOT-223 package, as well as the LM340-5.0 and LM340-12 in the surface-mount TO-263 package.

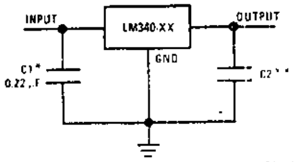
Features

- Complete specifications at 1A load
- Output voltage tolerances of ±2% at T_j = 25˚C and ±4% over the temperature range (LM340A)
- Line regulation of 0.01% of V_{OUT}/V of ΔV_{IN} at 1A load (LM340A)
- Load regulation of 0.3% of V_{OUT}/A (LM340A)
- Internal thermal overload protection
- Internal short-circuit current limit
- Output transistor safe area protection
- P⁺ Product Enhancement tested

Device	Output Voltages	Packages
LM140	5, 12, 15	TO-3 (K)
LM340A/LM340	5, 12, 15	TO-3 (K), TO-220 (T), SOT-223 (MP), TO-263 (S) (5V and 12V only)
LM7800C	5, 8, 12, 15	TO-220 (T)

Typical Applications

Fixed Output Regulator

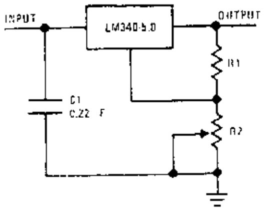


DS007781-1

*Required if the regulator is located far from the power supply filter.

**Although no output capacitor is needed for stability, it does help transient response. (If needed, use 0.1 µF, ceramic disc).

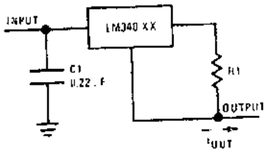
Adjustable Output Regulator



DS007781-2

V_{OUT} = 5V + (5V/R1 + I_Q) R2 5V/R1 > 3 I_Q,
load regulation (L_r) ≈ [(R1 + R2)/R1] (L_r of LM340-5).

Current Regulator

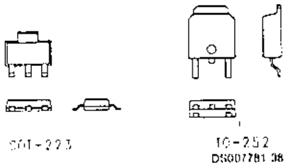


DS007781-3

$$I_{OUT} = \frac{V2\text{-}3}{R1} + I_Q$$

ΔI_Q = 1.3 mA over line and load changes.

Comparison between SOT-223 and D-Pak (TO-252) Packages



DS007781-38

Scale 1:1

Absolute Maximum Ratings (Note 1)

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/ Distributors for availability and specifications.

(Note 5)

DC Input Voltage	
All Devices except LM7824/LM7824C	35V
LM7824/LM7824C	40V
Internal Power Dissipation (Note 2)	Internally Limited
Maximum Junction Temperature	150°C
Storage Temperature Range	−65°C to +150°C
Lead Temperature (Soldering, 10 sec.)	
TO-3 Package (K)	300°C
TO-220 Package (T), TO-263 Package (S)	230°C
ESD Susceptibility (Note 3)	2 kV

Operating Conditions (Note 1)

Temperature Range (T_A) (Note 2)	
LM140A, LM140	−55°C to +125°C
LM340A, LM340, LM7805C, LM7812C, LM7815C, LM7808C	0°C to +125°C

LM340A
Electrical Characteristics

I_{OUT}= 1A, −55°C ≤ T_J≤+150°C (LM140A), or 0°C ≤ T_J≤+ 125°C (LM340A) unless otherwise specified (Note 4)

Symbol	Output Voltage		5V			12V			15V			Units
	Input Voltage (unless otherwise noted)		10V			19V			23V			
	Parameter	Conditions	Min	Typ	Max	Min	Typ	Max	Min	Typ	Max	
V_O	Output Voltage	T_J = 25°C	4.9	5	5.1	11.75	12	12.25	14.7	15	15.3	V
		P_D ≤ 15W, 5 mA ≤ I_O ≤ 1A	4.8		5.2	11.5		12.5	14.4		15.6	V
		V_{MIN} ≤ V_{IN} ≤ V_{MAX}	(7.5 ≤ V_{IN} ≤ 20)			(14.8 ≤ V_{IN} ≤ 27)			(17.9 ≤ V_{IN} ≤ 30)			V
ΔV_O	Line Regulation	I_O = 500 mA			10			18			22	mV
		ΔV_{IN}	(7.5 ≤ V_{IN} ≤ 20)			(14.8 ≤ V_{IN} ≤ 27)			(17.9 ≤ V_{IN} ≤ 30)			V
		T_J = 25°C		3	10		4	18		4	22	mV
		ΔV_{IN}	(7.5 ≤ V_{IN} ≤ 20)			(14.5 ≤ V_{IN} ≤ 27)			(17.5 ≤ V_{IN} ≤ 30)			V
		T_J = 25°C			4			9			10	mV
		Over Temperature			12			30			30	mV
		ΔV_{IN}	(8 ≤ V_{IN} ≤ 12)			(16 ≤ V_{IN} ≤ 22)			(20 ≤ V_{IN} ≤ 26)			V
ΔV_O	Load Regulation	T_J = 25°C, 5 mA ≤ I_O ≤ 1.5A		10	25		12	32		12	35	mV
		T_J = 25°C, 250 mA ≤ I_O ≤ 750 mA			15			19			21	mV
		Over Temperature, 5 mA ≤ I_O ≤ 1A			25			60			75	mV
I_Q	Quiescent Current	T_J = 25°C			6			6			6	mA
		Over Temperature			6.5			6.5			6.5	mA
ΔI_Q	Quiescent Current Change	5 mA ≤ I_O ≤ 1A			0.5			0.5			0.5	mA
		T_J = 25°C, I_O = 1A			0.8			0.8			0.8	mA
		V_{MIN} ≤ V_{IN} ≤ V_{MAX}	(7.5 ≤ V_{IN} ≤ 20)			(14.8 ≤ V_{IN} ≤ 27)			(17.9 ≤ V_{IN} ≤ 30)			V
		I_O = 500 mA			0.8			0.8			0.8	mA
		V_{MIN} ≤ V_{IN} ≤ V_{MAX}	(8 ≤ V_{IN} ≤ 25)			(15 ≤ V_{IN} ≤ 30)			(17.9 ≤ V_{IN} ≤ 30)			V
V_N	Output Noise Voltage	T_A = 25°C, 10 Hz ≤ f ≤ 100 kHz		40			75			90		µV
$\frac{\Delta V_{IN}}{\Delta V_{OUT}}$	Ripple Rejection	T_J = 25°C, f = 120 Hz, I_O = 1A	68	80		61	72		60	70		dB
		or f = 120 Hz, I_O = 500 mA, Over Temperature,	68			61			60			dB
		V_{MIN} ≤ V_{IN} ≤ V_{MAX}	(8 ≤ V_{IN} ≤ 18)			(15 ≤ V_{IN} ≤ 25)			(18.5 ≤ V_{IN} ≤ 28.5)			V
R_O	Dropout Voltage	T_J = 25°C, I_O = 1A		2.0			2.0			2.0		V
	Output Resistance	f = 1 kHz		8			18			19		mΩ
	Short-Circuit Current	T_J = 25°C		2.1			1.5			1.2		A
	Peak Output Current	T_J = 25°C		2.4			2.4			2.4		A
	Average TC of V_O	Min, T_J = 0°C, I_O = 5 mA		−0.6			−1.5			−1.8		mV/°C
V_{IN}	Input Voltage Required to Maintain Line Regulation	T_J = 25°C	7.5			14.5			17.5			V

140
ctrical Characteristics (Note 4)

C ≤ T_J ≤ +150°C unless otherwise specified

ol	Output Voltage			5V			12V			15V			Units
	Input Voltage (unless otherwise noted)			10V			19V			23V			
	Parameter	Conditions		Min	Typ	Max	Min	Typ	Max	Min	Typ	Max	
	Output Voltage	T_J = 25°C, 5 mA ≤ I_O ≤ 1A		4.8	5	5.2	11.5	12	12.5	14.4	15	15.6	V
		P_D ≤ 15W, 5 mA ≤ I_O ≤ 1A		4.75		5.25	11.4		12.6	14.25		15.75	V
		V_{MIN} ≤ V_{IN} ≤ V_{MAX}		(8 ≤ V_{IN} ≤ 20)			(15.5 ≤ V_{IN} ≤ 27)			(18,5 ≤ V_{IN} ≤ 30)			V
	Line Regulation	I_O = 500 mA	T_J = 25°C		3	50		4	120		4	150	mV
			ΔV_{IN}	(7 ≤ V_{IN} ≤ 25)			(14.5 ≤ V_{IN} ≤ 30)			(17.5 ≤ V_{IN} ≤ 30)			V
			−55°C ≤ T_J ≤ +150°C			50			120			150	mV
			ΔV_{IN}	(8 ≤ V_{IN} ≤ 20)			(15 ≤ V_{IN} ≤ 27)			(18.5 ≤ V_{IN} ≤ 30)			V
		I_O ≤ 1A	T_J = 25°C			50			120			150	mV
			ΔV_{IN}	(7.5 ≤ V_{IN} ≤ 20)			(14.6 ≤ V_{IN} ≤ 27)			(17.7 ≤ V_{IN} ≤ 30)			V
			−55°C ≤ T_J ≤ +150°C			25			60			75	mV
			ΔV_{IN}	(8 ≤ V_{IN} ≤ 12)			(16 ≤ V_{IN} ≤ 22)			(20 ≤ V_{IN} ≤ 26)			V
	Load Regulation	T_J = 25°C	5 mA ≤ I_O ≤ 1.5A		10	50		12	120		12	150	mV
			250 mA ≤ I_P ≤ 750 mA			25			60			75	mV
		−55°C ≤ T_J ≤ +150°C, 5 mA ≤ I_O ≤ 1A				50			120			150	mV
	Quiescent Current	I_O ≤ 1A	T_J = 25°C			6			6			6	mA
			−55°C ≤ T_J ≤ +150°C			7			7			7	mA
	Quiescent Current Change	5 mA ≤ I_O ≤ 1A				0.5			0.5			0.5	mA
		T_J = 25°C, I_O ≤ 1A				0.8			0.8			0.8	mA
		V_{MIN} ≤ V_{IN} ≤ V_{MAX}		(8 ≤ V_{IN} ≤ 20)			(15 ≤ V_{IN} ≤ 27)			(18.5 ≤ V_{IN} ≤ 30)			V
		I_O = 500 mA, −55°C ≤ T_J ≤ +150°C				0.8			0.8			0.8	mA
		V_{MIN} ≤ V_{IN} ≤ V_{MAX}		(8 ≤ V_{IN} ≤ 25)			(15 ≤ V_{IN} ≤ 30)			(18.5 ≤ V_{IN} ≤ 30)			V
	Output Noise Voltage	T_A = 25°C, 10 Hz ≤ f ≤ 100 kHz			40			75			90		μV
V_{IN} $_{OUT}$	Ripple Rejection	f = 120 Hz	I_O ≤ 1A, T_J = 25°C or	68	80		61	72		60	70		dB
			I_O ≤ 500 mA, −55°C ≤ T_J ≤+150°C	68			61			60			dB
		V_{MIN} ≤ V_{IN} ≤ V_{MAX}		(8 ≤ V_{IN} ≤ 18)			(15 ≤ V_{IN} ≤ 25)			(18.5 ≤ V_{IN} ≤ 28.5)			V
	Dropout Voltage	T_J = 25°C, I_O = 1A			2.0			2.0			2.0		V
	Output Resistance	f = 1 kHz			8			18			19		mΩ
	Short-Circuit Current	T_J = 25°C			2.1			1.5			1.2		A
	Peak Output Current	T_J = 25°C			2.4			2.4			2.4		A
	Average TC of V_{OUT}	0°C ≤ T_J ≤ +150°C, I_O = 5 mA			−0.6			−1.5			−1.8		mV/°C
	Input Voltage Required to Maintain Line Regulation	T_J = 25°C, I_O ≤ 1A		7.5			14.6			17.7			V